X X

Kursunoglu High Energy Physics 1972 vol. 5 -
Gatto Review on Tests QED

Berezin 2nd quantization (1966)

S-Matrix references

Shirkov A.J. Phys 31 755 (1963)
Oehme P.R. 125 745 (1962)
Stapp

Muon anomaly 1 part in 100,000 10 ppm.

Phys. Lett. 55B p. 420 (1975)

Barut : Electrodynamics & classical theory of fields & particles, 1964 (Macmillan classical)

Nobel Lectures 1965 Schwinger, Tomonaga & Feynman fld anecdotes

Bethe... Q. Mechanics of 2-electron systems RMP 35, 421 (1963)

S. Klar. Phil. Sci 40 (1973) 194.
Statistical Explanation, Ergodic Theory.

Velo, Wightman: constructive Q. Field theory, 1973.

Lloyd, Epistemological Studies in Contemporary Physics ed. Elkana, Wartofsky (1974) Dordrecht.

Schwinger Ann. Phys 11, 1 (1960) (gauge theories)

G.E. Emch (1984)

Mathematical and Conceptual Foundations of 20thC Physics — North-Holland

Survey of Mechanics, stat. mechanics, SR, GR, QM and QFT from abstract mathematical point of view — not enough detail to learn from, but good to note for reference.

— move to

Simms & Woodhouse Lectures on Geometric Quantization Springer Lecture Notes in Physics vol 53 (1976)

cf also M. ~~Foundations~~ Bunge: Foundations of Physics (1967) — somewhat similar in style to Emch, but more philosophical

N.E. Hurt Geometric Quantization in Action — D. Reidel (1983)

Very clear and comprehensive discussion including the mathematical background

J.A. Eisele : *Modern Quantum Mechanics with Applications to Elementary Particle Physics* (Wiley: New York) 1969.

Gives very detailed manipulation of Dirac matrices etc, good discussion of parity violation in β-decay of Feynman's integral eqn approach (to his dismay) used. particularly good on the Foldy-Wouthuysen transformation — all steps included and misprints corrected in the original papers refers to Kursunoglu. "Transformation of Relativistic wave equations" Phys Rev 101, 1419 (1956).

R. Shankar: *Principles of Quantum Mechanics* (Plenum: New York) 1980 gives particularly clear discussion of Feynman's path integral — defn of evaluation

G. Velo & A. Wightman *Constructive Quantum Field Theory* (Springer) 1973 report on Ettore Majorana Conference — detailed background to Shelter's 1976 course.

Combley (g-2) factors for muon, electron

Rep. Prog. Phys. 42 (1979) 1889

very good up-to-date discussion of experiment, theory with reference to Washington experiments of Dehmelt et al.

Pauli RMP. 15 p. 175. (1943)
Uehling P.R. 48 55 (1935)
Pauli, Rose PR 49 (1936) p 462.

Kemble & Present P.R. 44 1031 (1932) *
Pasternack P.R. 54 1113 (1938) *
Williams P.R. 54 558 (1938)
Houston P.R. 51 446 (1937)
Retherford, Richardson & Williams P.R. Soc. 174, 164 (1940) *
Breit P.R. 71, 984 (1947) *

References from J. Cushing 'Some Aspects of Current Methodologies in the Mobility of Science as Reflected in Quantum Field Theory and S-Matrix Theory'

L.D. Landau 'On Analytic Properties of Vertex Parts in Quantum Field Theory' Nucl. Phys. 13 (1959) 181-192

R.E. Cutkosky 'Singularities, Discontinuities of Feynman Amplitudes'

Chang & Fabri 'The Field Theoretic Definition of the Nucleon Potential - I'. N.C. 14 (1959) 540-55?.

D. Atkinson 'A Proof of the Existence of Functions that Satisfy Exactly Both Crossing & Unitarity - I. Neutral Pion-Pion Scattering - No Subtractions'. ~~A.A.~~ Nucl. Phys. B7 (1968) 375-408.
(Schauder Fixed point analysis SM.T.?)

Stapp "Bell's Theorem Without Reference"? N.C. 29 B (1975) 270-276.

P.W. Higgs Phys. Lett. 12 (1964) 132.
Phys. Rev. Lett. 13 (1964) 508.
P.R. 145 (1966) 1156.

Breakdown of Goldstone's Theorem for Gauge Theories

L. O'Raifeartaigh "Hidden Gauge Symmetry"
Rep. Prog. in Physics 42 (1979) 159–223.

Goldstone N.C. 19 (1961) 154

Goldstone, Salam, Weinberg P.R. 127 (1962) 965.
Proof of Goldstone's Theorem.

Chew "Hadron Bootstrap Hypothesis"
P.R. 4D (1971) 2330–2335.

P. Collins An Introduction to Regge Theory and High Energy Physics — CUP 1977 — very good updated account of his earlier reports on the subject.

G. Velo and A. Wightman (eds) : Constructive Quantum Field Theory : Lecture Notes in Physics vol. 25 (Berlin: Springer-Verlag) 1973.

mainly devoted to Euclidean field theory and QFT models

good discussion of Probability theory of stochastic processes by Reed to get ab score the work of Nelson (1972 onwards). Euclidean [illegible] [illegible] - [illegible] and by Dyson in discussing renormalization

J. Glimm and A. Jaffe Physics of Quantum Field models p. 133 - 198.

they gave the following basic references:

G.J.L: $\lambda(\Phi^4)_2$ without cutoffs I. P.R. 176 (1968) 1945

II. Ann. Math. 91 (1970) 362

III Acta Math 125 (1970) 203

IV J. Math Phys. 13 (1972) 1558.

Also Comm. Math. Phys. 22 (1971), 1.

See Wig. What is Renormalization? in Symposium on Partial diff. Eqs. Berkeley 1971. (Am. Math. Soc.)

See also - Quantum Field Models in Stat. Mech. and QFT ed. de Witt, Stora 1971

and Boson Quantum Field Models in Streater (ed) 'Maths of Contemporary Physics' 1972.

best paper on Euclidean Fermi fields is Osterwalder. — also Symanzik seems to be very nice too.

J. Rehren to Heymann's Condition d Notari

1973 — dedicated to Nene-

fund articles on history of QFT — earlier

an answer to Jordan for when at

2nd quantization.

[illegible] by Lehmann as [illegible]

— [illegible] of Glimm, Jaffe

on infinities on exact solns of

models theories. (p 430)

Glimm, Jaffé 1969–1972.

solve (2+1) dimensional theory exact:

ϕ^3, ϕ^4, $\bar{\psi}\psi(x)\phi$ without perturbation

Infinities appear in the exact solutions

as well as in perturbation theory. so it

is not perturbation expansion which is at

fault cf. Glimm, Jaffe, Spencer

P.R.D 5 2548 (1972)

cf Glimm, Jaffe Proc. Enrico Fermi
Local Q.T. - ed Jost (1969) (course 45(?)

Tachyons

Introduced by Bilaniuk, Deshpande & Sudarshan in Am. J. Phys. 30 (1962) 718

~~Difficulties discussed~~ by Causal anomaly discussed by

Pirani P. R. D1 (1970) 3221 this paper controverted by Parmentola & Yee P.R. D4 (1971) 1912

they use [illegible] have to describe complete scattering arrangement. Ed. Note

Difficulties treated by Feinberg P.R. 159 (1967) 1089.

Travelling Backwards in Time

R. Weingard. Synthese 24 (1972) p117

analyses Putnam's claim (J. Phil. 59 (1962) 658) that time travel is a conceptual possibility

are 3 electrons occurs at t_1 or one occurs

Feynman.

Ed is clearly adopted from Feynman. Is this possible of backward causation. W. says this is quite a different question.

Goldhaber & Smith a review article on
hypothetical particles Rep. Prog. Phys. 1975
[illegible] on Earth requires of [illegible] [illegible]
& observed by several different ~~[illegible]~~) [illegible]
each would [illegible] rotated [illegible], form a [illegible]
on line — answer seems to be
negative 1? - suppose [illegible]
and free position.

K. Schrader-Frechette

Atomism in Crises: An analysis of the current High energy paradigm. Phil. Sc. 44 (1977) pp 409-440

argues for Kuhnian crisis because

1.) old paradigm is unclear

2) paradigm fails to support normal problem solving research.

very muddled and confused paper.

all wrong points of detail.

J.C. Graves and J.F. Roper Phil. Sci. 32 (1965) 39.
'Measuring Measuring Rods'
argue as does ~~Ween~~ Putnam that Feynman interpretation is a natural one.
1) mysterious (unseen) processes are eliminated 2) reduced no. of entities 3) explains identity of e^+, e^-

But J. Earman 'On going backwards in time' Phil. Science 34 (1967) 211.
argues against Feynman for following reasons.
1.) e^+, e^- are not totally similar since e invariance is broken by weak interactions
2.) annihilation - creation are not explained.
annihilation is not inter relationship but into a photon

References to check:

Wheeler, Feynman: Direct particle interaction — Absorber Theory — RMP 21 (1949), 17 (1945) — Feynman RMP 20 (194[illegible] (Feynman theory)

Feynman P.R. 74 (1948) p. 939.

E.C.G. Stueckelberg. Helv. Phys. Acta. 14 (1941) p588, 15 (1942) p. 2

J. Earman. Aust. J. Phil. 50 (1972) (Tachyons)

Synthese 24 (1972) Causal anomalies

Rumnett. Phys. Rev. 1964 73 p 338 retrocausation

Chisholm, Taylor Analysis 20 73 (1960) "

Gödel RMP 1949 21 p 447 ; Einstein Schilpp Vol.

Reichenbach Direction of Time p 266 (comment on Feynman).

Earman ✓ Phil. Sci. 34 (1967) p. 211 objects to Feynman's e+-e annihilation retrocausation

Weingard Space, Time, Geometry 1973 ed Suppes. closed time-like world lines

Wiener ✓ Phil. Sci. 37 (1970) p 81, 37 pp. 223

Gardner et al ✓ Phil. Sci 36 (1969) — pre-established synchronization

Bonner, Ellis ✓ Phil. Sci 34 (1967) pp 116.

Earman ✓ Phil. Sci 41 (1974) (Backward Causation)

Fitzgerald Boston Studies (Pedges)
Vol VIII (1971)

Pirani P. R. D, 1, 3224 (1970) (")

Peres, Schulman Int. J. Theor Phys. 6, 377 (1972)
(cd)

Earman ✓ Covariance, Invariance, Frames & Relevance
Foundations of Physics 4 (1974) 267

A Garland ✓ RMP 48 (1976) 435 Big Bang!

Grunes, Rohel ✓ Phil. Sci 32 (1965) 39 Feynman & Wheeler
vindicated

Fierz, Weisskopf → Pauli vol.
Physics in 20th Century

Salam, Wigner → Dirac vol
Aspects of Q. Theory.

Schwinger Q.F.D. papers.

R.H.P. **Table of particles** April 1976

Bosons	Fermions
Mesons: pions 150, kaons 500, η 550	Baryons: Nucleons $\{p, n\}$ 950
+ resonances: ρ 750, ω 800, J/ψ 3,100	Hyperons: Λ 1100, Σ 1200, Ξ 1300, Ω 1650
	+ resonances: $\Delta(1232)$ 1250
Hadrons	
photon 0 ✓	Leptons
graviton (?) 0	neutrino, ν_e, ν_μ 0
W-particle (?)	electron 1/2
	muon 100
gluons (?)	quarks (?)

32 mesons
46 baryons
78

Masses to 50 MeV.

with antiparticles ~ 150 particles

Physics Reports

Higgs Phenomenology. Iravey, Worden. 34 (1977) 117–231

Colour Models of Hadrons Greenberg, Nelson.
32, (1977), 69-121

evidence of integral, coloured quarks

Quantum Chromodynamics W. Marciano and H. Pagels.
36 (1978) 137–276.

notes QCD due to Gell-Mann
" confinement makes colour degree of freedom as " unobservable ". It would be an
... in principle unobservable. ...
...
... [illegible]
... the fundamental entities were non-empirical
... mathematical constructs " very clear
discussion of modern theories — excellent
review of modern state-of-play.

gives references on conformal, scale invariance
(in discussion of renormalization proof)

Coleman, Jackiw. Ann. Phys. 67 (1971) 552
Mack. Nucl. Phys. Nuc. Phys. B5 (1968) 499
Mack, Salam Ann. Phys. 53 (1969) 174.
Kastrup. P.R. 142 (1966) 1060.

Reasons for Q.C.D.

Colour statistics

scaling properties

quark confinement mechanism — asymptotic freedom.

renormalizability.

phenomenological QCD — derived one out of basic theory

(1) Parton model.

(2) Bag model for confinement

(3) potential model.

(4) string model — glue forms flux lines between the quarks.

Detailed discussion of renormalizability, renormalization group etc.

3 sorts of regularization

1) Pauli Villars

2) lattice

3) dimensional

Exactly soluble 2-dimensional gauge theories

Detailed discussion of confinement studies ?

classical solutions – can be considered via path-integral formulation of quantization

Also Taylor Q. N. could be violated as a colour singlet divides into coloured states – possible confinement mechanism

Conclusion QCD provides a potentially rigorous QFT to justify the application of quark, parton models.
– there is "dogmatic optimism that a theory of strong interactions has been found"!

But QCD is very unproven.
the right questions have been put
in by hand. If theory fails it will be on dynamical grounds.

Also free quarks may exist at sufficient high energies

Perfect is a unified theory of all fundamental interactions — weak, e.m. strong and gravitational.

<u>Quantum gravidynamics</u>
gravitons (Bose)
gravitinos (fermions)

<u>Quantum chromodynamics</u>
quarks – coloured gluons.

<u>Quantum flavour dynamics</u>
Leptons, quarks and weak flavour-ful bosons (W-particles)

<u>Three-flavour quark field</u> has 4 flavours - SU(4)
and 3 colours (SU(3)) + up, down, strange, charmed.
red, white, blue.

<u>Vector gauge field</u>: of 8 coloured gluons
(do not carry flavours).

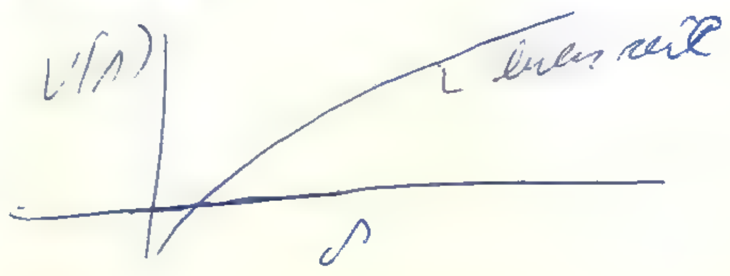
Colour symmetry is <u>local</u> (gauged)

Colour singlets exist which are bound states of gluons known as <u>glueballs</u> or quarkless hadrons (the flavour singlets)

quark confinement

In QED with abelian gluon, e-p face a attractive Coulomb law. field spreads out over all space.

In QCD with non-abelian gluons we might suppose self-interacting character of the gluon may entity a lower energy configuration in a tube of coloured flux between the quark and anti-quark. The rise the field energy in p.e. per unit e configuration is a linear function of the separation distance (constant force), the quarks are confined, i.e. energy required to separate a colour singlet state into a coloured state is infinite



More recent renormalization procedure is
due to Bogoliubov, Parasiuk, Hepp and
Zimmermann (BPHZ)

Reviews in Physics Reports

C.S. Sharma: Correlation energy in atoms — 26 C July 1976. Good critique of atomic calculations.

D. Rogovin, M. Scully Superconductivity & macroscopic quantum phenomena. 25 C June 1976. Good account of macroscopic wave functions

R. McLone. Semiclassical & electromagnetic theory effects in W.R. radiation 25 C May 1976 — good account of Jaynes - neo classical theory. Comments EPR — (cannot account for correlation effects)

RMP Bohr, Mottelson, Rainwater on Collective motion in nuclei, + discussion of Elliott model 48 (1976) no 3.

Refs to Elliott 1958 P. R. Soc. A 245, 128 & 562.

Additional reference of [illegible]

Ohnuki, Kamefuchi "Para-Fermi Field Theory"
P.R. 170 (1968) p1279.

derives relation of colored quarks to parafield models of hadrons.

Harik, Taylor P.R. 178 (1969) p2043

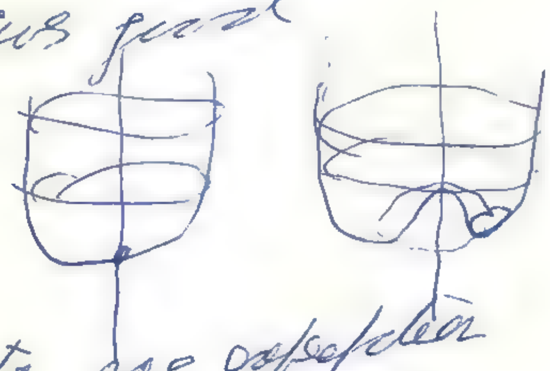
Cluster [illegible] sep.: separated systems may be treated as isolated systems.

Springer Tracts in Modern Physics

Lauman - 2, 3 nucleon systems
1976? - good account of [illegible]
models.

Physics Today March 1976 Heisenberg "The Nature of Elementary Particles" p 32

Physics Today June 1975 S. Weinberg "Light as a fundamental particle" — Good discussion of quantization — & light a fundamental particle. — discusses how little group goes from SO(3) to E(2) as vel. of particle tends to C — gives good illustration of broken symmetry



with indented bottom of bowl circular trough is stable. Position of ~~ball~~ ball corresponds to vac. expectation values of a scalar field, oscillation frequencies to scalar particle mass and the newly created rolling mode to a Goldstone boson of zero mass (can be created with zero input of energy). i.e. frequency of mode is ∞).

Gauge group	Vector field	Theory
U(1)	A_μ	Q.M.
U(2)	$A_\mu, W_\mu^{\pm}$	Y.M.
U(2) ⊗ U(1)	$A_\mu, W_\mu^{\pm}, Z_\mu$ — field appears by Higgs-Kibble mechanism.	

Weinberg is enthusiastic for gauge symmetry as fundamental principle of nature that governs interactions.

Scientific American

Y. Nambu: The Confinement of Quarks.
Nov. 1976. p. 48.

(1) Assume colour gauge symmetry with asymptotic freedom — refer to Politzer & Gross & Wilczek.

(2) String model.

3) Johnson MIT Bag model

4.) Wilson lattice-theory model.

K. Wilson P.R. D 10 2445 (1974)
proposes his lattice gauge model & quark confinement

Kogut & Susskind P.R. D9, 3501 (1974)
known physical picture of quark confinement in gauge theories (cf. Nambu article)

refer to Weinberg PRL. 31 494 (1973)
~~Gorter~~ Carter, Rogers & Susskind P.R.L 31 792 (1973)
P.R. D9 206 (1974)

for general idea
of quark confinement via gauge theory

Weinberg (1973)
refers to Gross & Wilczek PRL 30 (1973) 1343
& Politzer PRL 30 (1973) 1346

for crucial colour as [illegible] confinement &
asymptotic freedom in colour gauge [illegible]

In 1973 Gross, Wilczek, and Politzer ~~may~~
show how ~~colour gauge [illegible] symmetry~~ may
~~account for~~ scaling, confinement properties of
quarks - may result from colour gauge
symmetry (chromodynamics)

Glashow, Iliopoulos & Maiani (1970)
introduce charm

De Rújula, Giorgi and Glashow (1975)
develop colour gauge symmetry as theory of
quark interactions (chromodynamics)

1973 Gross and Wilczek, and Politzer
explain scaling, confinement properties of quarks

in terms of colour polynomials (chromopolynomials)

Gordon ??. (+ Putnam) 1974
Y Nambu: "The confinement of quarks" Sci. American
Nov 76. p. 48.

describes interaction between quarks (coloured) by non-abelian gauge field of massless vector gluons (of colour-anticolour pairs)

Confinement due to (1) asymptotic freedom or ultra-violet freedom as opposed to infra-red slavery (Politzer & Gross, Wilczek). force ~~unusual~~ remains constant until depleted in effecting glue-change, creates more quarks

(2) string model quarks attached to ends of massless rotating strings constant tension, pressure near Nielsen & Olesen string solutions

(3) MIT Bag due to Kenneth Johnson

(4) K. Wilson: lattice model of space-time quarks on lattice sites, colour gluon field propagates along st. lines (strings) forming chain

Reference to bag model Johnson et al.
P.R.D. 9 (1974) 3471, P.R. D 12 (1975) 2060

Colour gauge theory of gluons due
to de Rujula, Georgi, Glashow
P.R. D 12. (1975) 147.
confines [illegible], quark philosophy
" Many recent theoretical, experimental
developments seem to confirm the
latter philosophy"

Note colour gauge symmetry is
not spontaneously broken, gluons
are massless, but zero electric
source of colour fields – so gluons
are also confined

" Once upon a time there was controversy
in particle physics. There were some
physicists (Eden?) who denied the
existence of structures more elementary
than hadrons, and searched for a
self-consistent interpretation wherein
all hadron states, stable or resonant,

Agnese, Calvini P.R. 12 (1975) 3800

"gauge fields arising from space time symmetries and gravitational theories"

refers to Utiyama & also Kibble J. Math. Phys 2, 212 (1961) for extension of Utiyama to local Poincaré covariance.

⟹ were equally elementary. Others (e.g. Gell-Mann) appalled by the economy democracy of hadrons insisted on the existence of a small number of fundamental constituents and of simple underlying force law. In terms of these more fundamental things, hadron spectroscopy should be qualitatively described and essentially understood just as are atomic and nuclear physics"

R. Roman: Introduction to Quantum Field Theory. John Wiley & Sons Inc. New York (1969)

Part I discusses Lagrangian Field Theory

concludes with discussion of renormalization theory in terms of Schwinger's functional methods (dressing)

Part II deals with LSZ, Wightman axioms, Haag's theorem, analytic and finishes with current algebra

p. 466 "Therefore it may be possible, in principle, to determine the [illegible] e$_s$, e$_u$, e$_c$ by some self-consistent iteration method [illegible] or the [illegible] of the three (single) [illegible] relations. [illegible] the possibility of such [illegible] depends on whether the [illegible] Mandelstam coefficients $D(s, t, u)$ considered as a function of the three complex variables s, t + u [illegible] or [illegible] function [illegible] [illegible] [illegible] [illegible], of course, need [illegible] [illegible] [illegible] [illegible] separately"

Quantum Gravity : An Oxford Symposium.
ed. C.J. Isham, R. Penrose, D.W. Sciama

Good general introduction by Isham.
refers to Brill & Gowdy Rep. Prog. Phys.
33 413 (1970)

also Wheeler ed: Magic without magic:
Freeman (1972)

More recent article is:—
Ashtekar and ~~Geo~~ Geroch
Quantum theory of Gravitation
Rep. Prog. Phys. 37 (1974) 1211–12[illegible]

For superspace (space of all equivalence
classes of metrics (connected by smooth transformations)
i.e. a point in superspace is a whole
geometry – quantum fluctuations act in
superspace not a fixed point in subspace
as in ~~the~~ classical physics
cf also Caianiello, Fichler, Witten : eds
Relativity 1970.

References for Post 1953 renormalization theory

Mathews and Salam P.R. 94, 185 (1954) ✓
(dependence of zero fields)

Redmond
(eventual regulators in propagators) ✓
P.R. 112 1404 (1958)

Redmond & Uretsky Annals of Physics 9 106 (1960) ✓

Dyson proof of asymptotic expansion
P.R. 85 631 (1952) ✓

cf. also Hori Prog. Theor. Phys 8 569 (1952) ✓
Riddell P.R. 91, 1243 (1953) ✓

References for Källén

Källén Helv. Phys. Acta 25, 416 (1952) ✓
Lehmann N.C. 11 342 (1954) ✓
Stueckelberg & Petermann Helv. Phys. Acta 26 499 (1953) ✓

Gell-Mann & Low P.R. 95, 1300 (1954) ✓

cf. Streater references: —
Jaffe Comm. Math. Phys. 1, 127-49 ✓
2, 301-26 ✓
Hepp J. Math Phys. 6 1762 ✓ (rotation invariance paper)

Hurst Proc Camb Phil Soc. 48 (1952) 625 ✓
Hurst. Proc Roy Soc A 214 (1952) 44 ✓, Thirring Helv. Phys Acta 26 (1953) 33-52 ✓
divergence of perturbation series

References from Barton

LSZ. NC 1, 205 (1955), 6, 319 (1957) (in English) ✓

Haag. Mat Fys Medd 29 no 12 (1955) ✓
~~Hall~~ & Wightman P.R. 101, 860 (1956) ✓
Wightman Mat Fys Medd. 31 no 5 (1957) ✓
Greenberg P.R. 115, 706 (1959) ✓
Wightman & Schweber P.R. 98, 812 (1955) ✓

Dispersion Relations

Hamilton Prog. Progress in Nucl. Phys. 7. (1959) 16
(Early history)

Axiomatic S-Matrix theory:
Stapp in J. Math Phys. 6, 827, 845, 852 (1965) 22 23
Olive P.R. 135 B 745 (1964) 1303. 24
Stapp. P.D. 3 (1971) ~~(1971)~~
Mandelstam. ~~N.C. 15 658 (1960)~~
Ann. Phys 21 302 (1963) 18 ✓
(CPT theorem and Analyticity of 2nd kind.)
Rep. Prog. Phys (1962) Review article p. 99-162. ✓
Zagolinski and Stapp (macrocausality → analyticity) Comm. Math Phys. 14 15 (1969)

Gale: [illegible]'s Monadology: J. Hist. Ideas
35 (1974) 339.

Weekes v Heck P.R.L 24 (1320) 1970.
Lemme v Wright P.R.D 8 3171

Gell-Mann, Goldberger & Thirring P.R. 95 1612 (1954)

Toll - P.R. 104 1760 (1956) | Goldberger P.R. 97 508 (1955)
99 979 (1955)

References from Jost

S-Matrix Philosophy Bremig & Haag
Fortschr Physik 7 (1959) 183

verification of dispersion relations:-
Noyes & Edwards P.R. 118 (1960) 1409

Mandelstam on analyticity from perturbation theory
P.R. 112 (1958) 1344
115 (1959) 1741

from axiomatic field theory
N.C. 15 (1960) 658.

Bonn papers of Heisenberg on S-Matrix
Z. Physik 120 (1943) 513, 673.

CGLN on π-N system.
P.R. 106 (1957) 1337

Chew & Low P.R. 101 (1956) 1570, 113 (1959) 1640.

Low P.R. 97 1392 (1955)

Wick P.R. 102 (1956) 1174, 100 (1955) 1503

Abers & Zemach P.R. 131 2305 (1963) nn* Zachary ✓
Zachariasen & Zemach P.R. 128 849 (1962) ρ Bootstrap ✓

Regge (1959) N.C. 14 951 ✓

Chew & Frautschi P.R.L. 7 394 (1961) ✓
Chew & Mandelstam P.R. 119 467 (1960) ✓
Chew, Frautschi & Mandelstam P.R. 126 1202 (1962)
Hamilton & Woolcock R.M.P. 35 (1963) 737 ✓
(cycles c.c.l.n)

not inclusive Donnachie Rep. Prog. Phys. 36 (1973) 695 PN review ✓
Eden " " " 34 (1971) 995 Regge review

Donnachie Hamilton & Lea P.R. 135 B515 (1964) ✓
Donnachie & Hamilton ann. Phys. 31 410 (1965) ✓
D. Bowler / Coulomb interaction (Pauli) Rep. Prog. Phys (1972) 34, 491 ✓

Kronig: J. Optical Soc. America (1926) 12 547 (all wonders)
Kramers Physica 12 543 (1946) ✓
~~Kramers:~~ Kronig Physica 12 543 (1946) ✓
Korff & Breit R.M.P. 4 471 (1932) (no derivation of dispersion relations)
refer to Wolf & Herzfeld Handbuch der Physics
Kramers. Atti Congr. Intern. Fisici Como 3 545 (1927) ✓

Zahar B.J.P.S. 24 (1973) p. 95.

The double heuristic role of mathematics in Science

Z says physics has heuristic function in stimulating mathematics (cf invention of calculus or vector analysis)

What about reverse process.

(1) maths may suggest a physical principle
cp M's route to Maxwell's equations & his introduction of the displacement current.

(2) We may seek to find a realistic interpretation to mathematical quantities used in peculiar theory.
cp. Lorentz → L.F.C. as a real dilation contraction not just a mathematical transformation, → M.F.H from which L.F.C. follows.
or Dirac → -ve energy soln → positrons.

Stapp H.P. P.R. 125 (1962) 2139 – 2162

"Derivation of the CPT Theorem and the Connection between Spin & Statistics from Postulates of the S-matrix theory"

Comments on asymptotic postulate:

"Physical asymptotic means that only regularities in the physical theory are those required by unitarity (these include the usual conditions are called regularities). This asymptotic requirement evidently contains some extraction of the usual locality argument. ... The postulates demand the of asymptotic rules [however] to be larger than the as that can be deduced from field theory. If this were the case the two theories would be different mutually incompatible systems. Indeed, then in the expectation the apparent inconsistencies of field theory are expected to be removed as a result of weakening the locality argument."

Chew G. F. & Frautschi S. C. P.R.L. 8 (1962) 41–44.

" Regge Trajectories and the Principle of Maximum Strength for Strong Interactions":

Explain the principle from the point of view of Regge theory.

" All of strong-interaction physics would flow from:

(a) the principle of maximal analyticity of the S-matrix in angular as well as linear momentum

(b) the principle of maximum strength

(c) the conservation of B, S & I. There should be no arbitrary dimensionless parameters and aside from the constant of length (or mass) to be added to ħ & c; there are no elementary particles"

C & F believe (b) & (c) may follow from (a).

References for Kronig[?]

Old view of renormalization:
Källén Helv. Phys. Acta. 25 416 (1952)
Lehmann N.C. 11, 342 (1954)

new view
Stueckelberg, Petermann Helv. Phys. Acta 26, 499 (1953)
Gell-Mann, Low. P.R. 95, 1300 (1954)

critique of field theory:
Landau et al. N.C. 13, Suppl 3, 80 (1956)
" Niels Bohr, Theoretical Physics, 1955

Dispersion relations
Mandelstam Rept. Prog. Phys 25, 99 (1962)

Critique of this point in
V.B. Adamskii: Soviet Phys. Usp. (English translation) 4, 607 (1962)

Streater & Wightman PCT, Spin & Statistics, & All That
(1964)

~~Chapter I~~ In Intro. S, W. refer to Dirac, Jordan, Heisenberg, Pauli formulation of rel. QFT. Consistent description not expected, since they were busy quantizing a classical theory calculating ∞ e.m. [illegible] of point particles

Main Problem of QFT is to Kill it or cure it.

Reference to the Field version (Field Society)

cf. Shakers, New England sect who "built good & non-scientific; solid barns & led celibate lives, ~~of~~ & calculating & proving rigorous theorems & calculating no cross-sections".

Chapter I super-selection rules simple & not unclear [illegible] or not physically realizable. Hilbert space splits into coherent subspaces

Symmetry operators defined à la Wigner (rigorous theorem not proved)

— Invariance of Lorentz, Poincaré Groups

Chapter IV

Mathematical tools

Defn of distribution as generaliz. of function

$$T(f) = \int T(x) f(x)\, dx \quad \forall f \in S$$

S is set of test functions.

$T(f)$ is a distribution (continuous linear functional on S)

$T(x)$ is a function

Tempered distributions.

f is complex-valued, ∞ differentiable which, and derivatives, $\to 0$ at ∞ faster than any power of the Euclidean distance.

Derivative of a distribution $\frac{\partial T}{\partial x}(f) \overset{Def}{=} -T\left(\frac{\partial f}{\partial x}\right)$

Retarded Green's fn

Laplace transform $g(u) = \int_0^\infty e^{iuk} f(k)\, dk$

is a boundary value of a holomorphic function reg. the Laplace transform

$$g(x+iy) = \int_0^\infty e^{ik(x+iy)} f(k)\, dk.$$

which is holomorphic in upper half-plane $y>0$

W. generalizes this to functions of several complex variables. 2

Theor. 2.4. $F(C^n)$ is holomorphic iff it is (p51)
continuous, holomorphic in each variable separately
in all variables together

└ not necessary by Hartog's theorem
cp. Bochner, Martin ch. VII.
Hartog's theorem not true for ∞ diff. functions.
(cf. Kaudelka ?)

on p 87 discussion of non-separable Hilbert spaces.
on ie. ∞ tensor product of separable H-spaces.
(∞ no. of degrees of freedom $\not\Rightarrow$ nonseparable)
— also decomposition based on Peter's article

Ref: A.S. Wightman: analytic functions of several
complex variables pp 159–221
Dispersion Relations, Elementary Particles,
Wiley, New York (1960)

Ch. 3 dealt with fields, vac. expectation values. — observables are smeared operators (cf Bohr, Rosenfeld) i.e. $E(x,t) \rightarrow E(f)$

function distribution

assumes microscopic causality or local commutativity.

What about canonical quantization:
not allowed in terms of operators smeared over space and time.
we assume instead smeared fields give all observables. i.e. same.
any state is derived from vacuum by operating with polynomials in smeared fields $P(\phi_1(f), \phi_2(g) \ldots)$

W.S. do not discuss scattering. Also asymptotic conditions to Haag, Ruelle assume
$H = H^{in} = H^{out}$ (cf JOST book)

various expectation values we depend 3

$(\Psi_0, \phi_1(x_1) \cdots \phi_n(x_n) \Psi_0)$ [illegible] reconstruction theorem we can always construct a field theory from a string of Wightman functions. (i.e. proof the theory of its vac. exp. values)

Ch IV deals with general theorems of Rel. Q. F. T.

(1) PCT theorem.

(2) Spin-statistics theorem — theory of Fermi transformations

(3) Haag's theorem:

For interaction we assume, since $\phi(x,t)$, $\phi_{in}(x,t)$ satisfy same equal-time commutation relations,

$$V(t)\,\phi(x,t)\,V(t)^{-1} = \phi_{in}(x,t). \qquad (1)$$

The dependence of V reflects presence of interactions

$$S = \lim_{t\to\infty} V(t)\,V(-t)^{*}.$$

But there may be inequivalent reps of the commutation relations, so existence of ν is not necessary, but possible. Haag's theorem says it is impossible unless $\phi(x,t)$ is itself a free field there is no V interlying (i

In effect "Renormalization gets mixed up with the dynamics in the sense that the dynamics determine which representation of the canonical commutation relations we use".

holds equal time commutation relations make no sense, fields must be smeared in time as well as space.

Final realization Borchers classes

different fields which have same S matrix etc

V.B. Ruelle "We have eliminated all theories where field is non-existent".

W. gives v. gd Bibliography:

PCT theorem 1st proved by Lüders (suggested by Zumino)
Dansk Mat. Fys. Medd. 28, 5 (1954)

proved if P is a symmetry then CT is a symmetry

Pauli first proved PCT is always a symmetry
in Niels Bohr & the Development of Physics
W. Pauli (ed) Pergamon, 1955.

Spin-statistics due to Fierz (1939) & Pauli (1940)
general proof due to Lüders & Zumino (1958)

Haag's theorem "On Q. Field theory" Dan Mat Fys
Medd 29, 12 (1955)

generalized in
Hall & Wightman, M.F. Medd Kgl. Dan. Vid Selsk.
31, 5 (1957)

Haag-Ruelle theory in
R. Jost, General Theory of Quantized Fields
1963

Note: on p16 W & S refer to old-fashioned view of symmetry $A \to \hat{A}'$ when discussed exp. of vectors etc.

$\Rightarrow$ unitary transformation of states

But anti-unitary symmetries also important — best dealt with by "direct physical way" of Wigner. But these can be observed under selection rules which are "rather curious". (p 17) Need these to describe symmetries which are not physical symmetries.

Physical symmetry $\longrightarrow$ observable symmetry.

Does observable symmetry $\to$ physical symmetry (probably yes ?)

The anomalous magnetic moment of the muon
by Farley. Contemporary Physics (1975) 16 p 413
gives complete references
refer to Rich & Wesley R.M.P. (1972) for 44 250
the electron anomaly
& Bailey et al. Phys Lett. B, 55, 420(1975) for latest
muon results.

Reference on Conformal group

Salam & Mack Ann Phys (N.Y.) 53, 174 (1969)

Salam & Isham? Ann. Phys. 67 552 (1971)

& to Zeeman on Causality J. Math Phys. 5, 490 (1964)

look at Barut Electrodynamics & classical theory of fields & particles 1963
and Barut The Theory of the scattering matrix 1967
good solid account with detailed derivations
& good mathematical appendices

Callan PR D2 1541 (1970)

Gross, Wilczek PR ~~D8 3497 (1973)~~, D8, 3633

D9 980 (1974)

Sequel, less interesting

Intro. to [illegible]

Gross, Wilczek

Fu. AS.F.C. theories [illegible]

Veneziano Phys Rep 9C no 4 (1974)

Good discussion [illegible] of dual models

Politzer Asymptotic Freedom: an approach to Strong Interactions: Phys. Rep. 14C no 4 (1974)

discusses gauge theories, renormalization group methods.

Mandelstam, Yan PRD 1. 1035, 1617, 2402 → 187, 2159 (1969)

Use field theory rules for partons. parton-like asymptotic behaviour from local field theory.

Bjorken Paschos: D1 3151 (1970)

179 1547 (1969)

185, 1975 (1969)

Salam, Wigner Aspects of Quantum theory ed.
(1972) Festschrift for Dirac. Bibliography of Dirac.

Good article by Jost. "Foundations of quantum theory" refers to Wentzel.

note Dirac's 1932 paper offering Heisenberg Pauli quantization of the electron field.

Proc. Roy Soc. A136 453 (1932)

– lead on to the Dirac - Fock - Podolski papers for quantizing a system of electrons

ASK Pais Theory of the electron 1897-47

"We cannot [therefore] suppose the field to be a dynamical system on the same footing as the particles"

Heisenberg, Pauli Z. f. Phys. 56 (1929) p. 1.

Introduction In Q. theory it has not until now been possible
to consider from a single view point and to unite without
contradiction all electrical and mechanical phenomena, electro-
magnetic interaction with the field, radiation interaction on
the atom. In particular it has not been possible to
allow for the finite propagation speed of electromagnetic interaction
correctly. The present work aims to fill these gaps.
For this therefore it will be essential to use
a rel.-invariant formalism which allows us to treat
interaction between matter and field as well as particles
on footing. This problem appears formally very difficult,
complete of the more. rel. formulation of the Dirac problem.
and we will reach a satisfactory solution and after
an elucidation of these fundamental difficulties.
Nevertheless the calculation effort can further
be separated off — perhaps it can be solved
by very correspondence principle.
It is known in classical field theory that a
rel. formulation of many particle problem of Hamiltonian
methods is not possible.

FJM Farley: The Status of QED

Rivista del Nuovo Cimento 1 (1969) 59–86.

Corinaldesi Introduction to Dispersion Relations

N.C. Suppl. [10] 14 (1959) 3

(vol. includes article by Haag et al on axiomatic field approach

Pauli (ed): Niels Bohr, the Development of Physics.

includes Pauli on QFT

Lüders " on the Quantum Theory of Fields

Rosenfeld " On quantum Electrodynamics"

Dirac. PRS 112 (1926) 661. "On the theory of QM"

discusses many-particle systems — proves F.D. statistics, B.E. equivalent to symmetry props of wave functions

p 666 "It would appear to be possible to build up an electromagnetic theory in which the potentials of the field at a specified point $x_0\, y_0\, z_0\, t_0$ in space-time are represented by matrices of constant elements that are functions of $x_0\, y_0\, z_0\, t_0$"

Dirac PRS 113 (1927) 621
"The Physical Interpretation of the Quantum Dynamics"

discusses general transformation theory and introduces the δ-function (refers to Lanczos work on continuous matrices) — studies ~~[illegible]~~ of q-numbers by c-numbers.

Dirac. P.R.S. A 117 (1928) 610–624.
introduces the Dirac eqn — gives an explanation of "duplexity" phenomena: from requirements of both relativity & the general transformation theory".
Difficulties of Klein-Gordon eqn + the eventual application to hydrogen atom — brilliantly dealt with in this paper.

Dirac P.R.S. A 118 (1928) 351–361.
(communicated 1 month later exactly)
derivation of conserved current — selection rules, intensity formulae for multiplet & Zeeman effect.

Dirac P.R.S. A 126 (1930) 360–365.
"A theory of electrons & protons":
first says "electron with negative energy moves in an external field as though it carries a positive charge.
If negative energy electron related to a proton — refers to Weyl for this suggestion Z. f. Phys. 56 (1929) 332.

we cannot really assert -ve energy electron *is* a proton, otherwise electrons could turn into protons by direct transition completely until conservation of charge. & other difficulties
Dirac then proposes his hole theory.
Assume all negative energy states are filled except for a few holes.
" a hole in a region that is otherwise saturated with electrons is much the same thing as ~~a~~ single electron in a region that is otherwise devoid of them.
What about electric field due to negative energy electrons — Dirac takes ρ in M's eqns as "departure from the normal state of electrification of the world". Dirac gives handwaving argument for asymmetry in masses of electron, proton (this was later disproved by Weyl) Ends paper by discussing full detailed description of intermediate states of -ve energy (inadequate for *not* describing these states. cf Klein-Nishina & Compton scattering) here refers to possibility of electron-proton annihilation

Oppenheimer P.R. 35 (1930) p. 562–563. (letter)
raises a number of objections to Dirac's
hole theory of the proton.
He argues that scattering of light by electron and
proton in Thomson limit (long λ) should
give same results – actually in ratio of
square of masses.
Also calculates mean life of matter
against proton-electron annihilation
→ 10^{-10} secs. O. proposes protons
& electrons are 2 independent particles
& assumes negative energy states for
both particles are normally completely
filled (Note first reference to anti
anti protons here)
detailed calculation on e-p annihilation
rate given by O. in P.R. 35 (1930) p. 939–947.
"Two notes on the probability of
Radiative transitions".

Dirac PRS A133 (1931) p. 60–72.
"Quantized singularities in the electromagnetic Field":

"The steady progress of physics requires for its theoretical ~~foundation~~ formulation a mathematics that gets continually more advanced . . . modern physical developments have required a mathematics that continually shifts its foundations & gets more abstract. Non-Euclidean geometry & non-commutative algebra, which were at one time considered to be purely fictions of the mind & pastimes for logical thinkers, have now been found to be very necessary ~~the~~ for the description of general facts of the physical world . . . advance in physics is to be associated with a continual modification & generalisation of the axioms at the base ~~the~~ of the mathematics rather than with a logical development of any one mathematical scheme on a fixed foundation."
[as ~~attempted~~ was adopted in last century].

"The most powerful method of advance that can be suggested at present is to employ all the resources of pure mathematics in attempts to perfect & generalize the mathematical formalism that forms the existing basis of theoretical physics, and after each success in this direction, to try to interpret the new mathematical features in terms of physical entities (by a process like Eddington's Principle of Identification)"

Dirac's sees his hole theory as exemplifying this methodology — a physical interpretation of the -ve energy states already necessitated by the formalism.

Refers to Weyl. Gruppentheorie und Quantenmechanik p.234 (1931) he finds + & -ve particles have same masses. D. credits Oppenheimer with suggestion that all negative energy states are filled. "An encounter between 2 hard γ-rays (-- could lead to the creation simultaneously of an electron & anti-electron"!

D. goes on to consider possible connection between smallest charge & smallest magnetic pole (monopole)

There's theory allowing for the existence of monopoles. He says rather plaintively "Under these circumstances one would be surprised if Nature had made no use of it"

D. concludes with question "Why isolated magnetic poles are not observed. Possible force of attraction between poles of opposite sign is so large that ~~only~~ that" "the very large force may probably account for why poles of opposite sign have never yet been separated"

Dirac PRSA 136 (1932) p. 453–464.
Relativistic Quantum Mechanics.
Dirac criticizes Heisenberg-Pauli Q.E.D. for not distinguishing particles, fields "the field should appear in the theory as something more elementary & fundamental".
Referring to Heisenberg's claim to base Q.T. on observables he says "Strictly speaking, it is not the observable quantities that form the building stones of Heisenberg's algebraic scheme, but rather certain more elementary quantities, the matrix elements, having the observable quantities as the squares of their moduli. The extra phase factors introduced in this way are essential (my italics)."
Dirac treats particles by 1st quantization, then quantizes the e.m. field.
D. also criticizes H-P theory for involving many quantities which are unconnected with results of observation and which must be removed from consideration if one is to obtain

a clear insight into the ~~conceptually~~ underlying physical relations !!

Fermi R.M.P. 4 (1932) 87–132.
Treats Dirac's radiation theory
[illegible] review Q.E.D. with
subsidiary conditions – not
[illegible] of [illegible] – [illegible]
bibliography refers to Waller
Z. f. Phys. 62, 673 (1930) for
calculation of self-energy of electron.

References

Lamb shift Expts

Lamb, Retherford P.R. 72 (1947) 241
75 (1949) 1325, 1332
79 (1950) 549
81 (1951) 222.
85 (1952) 259. 86, 1014 (1952)
Triebwasser, Dayhoff, Lamb 89 (1953), 98, 106

Lamb Rep. Prog. in Physics 14 (1951) 19.
Robiscoe, Shyn: P.R. 168 (1968), 4, P.R.L. 24 (1970) 559

Theory Kroll, Lamb P.R. 75 388 (1949)
French, Weisskopf 75 1240 (1949)
Feynman 74, 1430 (1949) correction 76 769 (1949),
Fukuda, Miyamoto, Tomonaga Prog. Theor. Phys 4 (1948) 47, 121.

$\alpha(Z\alpha)^5$ Baranger, Bethe, Feynman. 92 482 (1953)
Karplus, Klein, Schwinger 86, 288 (1951)
Salpeter (recoil) 89, 92 (1953)
4^{th} order α^2 Baranger, Dyson, Salpeter P.R. 88 680 (1953)
Bersohn, Weneser, Kroll, P.R. 86, 596 (1952)
91, 1257 (1953)

$\alpha(\alpha Z)^6$

Layzer P.R.L. 4, 580 (1960)
Fried, Yennie P.R.L. 4 ~~583~~ 580 (1960)

More accurate α^2 initiated by ~~Brodsky~~ Applequist & Brodsky PRL 24, 562 (1970)

Electron anomaly

Theory Schwinger 73 416 (1948)
Karplus, Kroll 77, 536 (1950)
Ann d Phys 5, 26, (1958) Sommerfield P.R. 107, 328 (1957)
Petermann Nucl. Phys. 5 677 (1958) Helv. Phys. Act. 30, 407 (1957)
Kroll (unpublished) (1957)

Expts Hyperfine studies Nafe, Nelson & Rabi P.R. 71 (1947) 914.
Interpretation as anomalous moment
Breit 72 (1947) 984, 73 (1948) 1410 ✓ [illegible]
Zeeman splitting Foley, Kusch P.R. 72 (1947) 1256
73 (1948) 412
74 (1948) 250.

T.A. Welton, P.R. 74 (1948) 1157 – 1167

Some observable Effects of the Quantum-Mechanical Fluctuations in the electromagnetic Field.

gives classical picture of zero point fluctuations in E, B giving rise to a $\langle(\Delta r)^2\rangle$ av. for electron which gives a level correction expected from $\langle V(r + \Delta r)\rangle_{av}$.

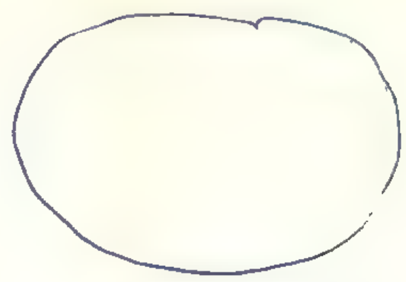
But effective magnetic moment due to anomalous [illegible] of spin is of wrong sign – discrepancy due to magnetic interaction of electron with the filled – ve energy states of the vacuum. (attributed to Koromboff.)

2. Koba P.T.P. 4 (1949) 319 – 330.

Semi-classical Treatment of the Reactive Corrections. I.

explains correct sign of magnetic moment by allowing for the binding of electron oscillation of electron reduces magnetic moment, oscillation of positron (zitterbewegung) increases magnetic moment

Welton
effect.



increased
effective diameter
due to Zitterbewegung.
opposite spin
; twice negative
of Welton effect

Oppenheimer, J.R. "Note on the theory of the interaction of field and Matter". P.R. 35 (1930) p. 461 – 477.
discusses self energy of electron, concludes that levels and difference between levels are shifted by infinite amounts.

Pauli, W. "On Dirac's New method of Field Quantization" R.M.P. 15 (1943) p. 175–2[illegible]
discusses the Dirac-Wentzel λ-limiting process. In discussing self-energy Pauli says "It is the author's opinion that this difficulty could be overcome only by using, instead of the λ-limiting process, a new, probably purely quantum theoretical method". Note that Pauli is referring to the electron self-energy in hole theory which is still logarithmically divergent even after Dirac's λ-limit and quantization with indefinite metric

E.A. Uehling "Polarization Effects in the Positron Theory" P.R. 48 (1935) p. 55 - 63.

Uehling discusses modification of Maxwell's equations due to vacuum polarization using the Heisenberg relativistic formalism (Heisenberg, Zeits f. Physik 90, 209 (1934) following a suggestion of Dirac, Proc. Camb. Phil. Soc. 30, 150 (1934). Method is also equivalent to Furry & Oppenheimer P.R. 45, 245 (1934)

Uehling discusses change in Coulomb law between two charged particles (increased repulsion. He discusses displacement of energy levels - both to increased separation of doublet lines in Balmer series which is opposite in sign, and "too small" by a factor of at least 2×10."

refers to Kemble, Present (1933) for origins of the hydrogen anomaly.

Pauli and Rose M.E. "Remarks on the Polarization Effects in the Positron Theory". P.R. 49 (1936) p. 462-

obtains simpler derivation of Uehling's result.

Interaction energy between charged particles

is $V(r) = z'z''e^2(1/r - \alpha/\pi\, U(r))$

$U(r)$ falls off exponentially for $r \sim \hbar/mc$

and is negative in region, so $V(r)$

in greater than Coulomb.

$U(r)$ is function first calculated by

$U(r)$ also given by
$\delta\bar{J}\lambda(x') = \alpha/4\pi^2 \int U(r)\, \nabla^2 \bar{J}\lambda(x'')\, dx''$ $\quad r = |x' - x''|$

we have omitted ∞ of term
$\delta\bar{J}\lambda(x) = \mathrm{Const} \times \bar{J}\lambda(x)$.

Kemble E.C. & Present R.D.

"On the Breakdown of the Coulomb Law for the Hydrogen atom:" P.R. 44 (1933) p. 1031–32.

refers to anomalies in doublet separation in Balmer series for hydrogen from Stark effect measurements

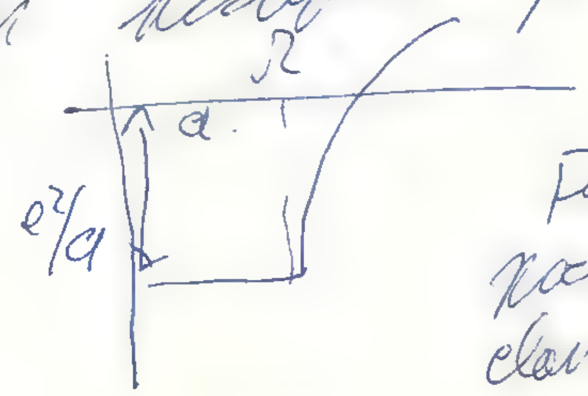
by Kent, Taylor & Pearson P.R. 30 266 (1927)

W.V. Houston, Astrophys. J. 64 81 (1926)

Spedding, Shane & Grace P.R. 44 58 (1933)

Houston & Hsieh Bull. Am. Phys Soc. 8 no. [illegible] (1933)

Consider modified potential



Find $a \approx 5 \times 10^{-12}$ cm much larger than classical electron radius 2×10^{-13}.

S. Pasternack "Note on the fine structure of H_2 and D_2". ~~the~~ P.R. 54 (1938) p. 113.

refers to letter with confirming discrepancy.

Houston & Hsieh P.R. 45 263 (1934)

Williams, Gibbs P.R. 45 475 (1934)
Kopfermann, Naturwiss. 22 218 (1934),
Spedding, Shane, Grace. P.R. 47, 38 (1935)
Houston P.R. 51 446 (1937)

Then recent work by *Williams P.R. 54 558 (1938)
confirm discrepancy in case of deuterium -
Paschen-Back groups exactly for H_2 is
a_2 & a_2 5 level displaced
upwards by .030 cm^{-1}. "[This] would
seem to point towards some perturbing
interaction between the electron & the
nucleus". Too large to be due to
finite size of electron & proton.

* Williams open to Bethe's suggestion
discrepancy was due to Radiative fluctuations
— much too small to account for
the discrepancy.

J.W. Drinkwater, Sir O. Richardson & W.E. Williams

of King's College London P.R.S. A 174 (1940) p. 164–188
used an reflexion echelon grating whereas previous was used a Fabry-Perot interferometer.
they conclude some support for Pasternack's suggestion but "we conclude that no real evidence has yet been obtained to show that the fine structures depart substantially from the values calculated from Dirac's equations."

Lamb W.E. Jr and Retherford R.C.
P.R. 79 (1950) 549–572.
"Fine structure of the Hydrogen Atom". Part I
gives background to their 1947 experiment
First in a series of 6 papers on precision
measurement – culminated in Triebwasser,
Dayhoff & Lamb (1953)
Refer to early spectroscopic evidence, refer
to Kopfer's series (1949) for spectroscopic
confirmation of level shift.
Microwave experiments suggested in 1928
by Grotrian. Attempts made in Germany
1932–1935 by Betz and Haase.
L & R read these and applied
new measurement techniques developed
during the war.

~~theory developed~~

Salpeter E.E. P.R. 89 (1953) p. 92–97.
"The Lamb Shift for Hydrogen, Deuterium"
summarizes theoretical work up to 1953.

2 approximations 1) relativistic coupling terms and
2) approximate treatment of Coulomb field powers of αZ.

1st rel. calculation by Kroll, Lamb, French &
Weisskopf. gave results ≈ 6 Mc/s. too low.

Then more accurate treatment of Coulomb field + 4th order (α^2) corrections to radiation coupling yield value $\frac{1}{2}$ Mc/s below Lamb's final result.

By 1960 two improvements
(1) revised 4th order anomalous moment (Sommerfield, Petermann (1957)
(2) More accurate treatment Coulomb field by Layzer (1960) & ~~Fried~~ Fried and Yennie (1960) gave good agreement

But then new experiments by. Robiscoe et al (1968) (Cosens) Kleiman, Shyn (1970) who also revised Lamb's results, gave new expt. value. near to 1057.9 instead of 1057.8 so old theory at 1057.56 × quoted by A. Maquet & Brodsky. was just too low. when this was broken in 1970

Appelquist & Brodsky calculated α^2 terms and found disagreement with calculation of Soto (1966) and their new value was 1057.91 ± 0.16, so very close to experiment. Further refinements in period 1970–1972 increased precision of theory to the value quoted in L.S. & P. viz. 1057.911 ± .012, so theory now 5 times as accurate as the experiment.

Nobel Prize lectures 1965

Tomonaga explains his debt to Dirac's ~~many~~-t multiple time formalism — extended to multiple times for fields (Dirac used particle description for electrons). Tomonaga says he began calculating Lamb shift after hearing about it "through the popular science column of a weekly U.S. magazine".

Feynman v. good account of early work with Wheeler on absorber theory of radiation → Lagrangian electrodynamics → ~~elag~~ space-time point of view.

anecdote re Slotnick calculation of electron-neutron scattering with Feynman checked out the problem needed!" The next day at the meeting I saw Slotnick and said 'Slotnick, I worked it out last night, I wanted to see if I got the same answers as

you do ...." and he said " what do
you mean you worked it out last night,
it took me six months" ~~and, he said,~~ "
~~what do you mean you worked it out~~
~~last night, it took me six months!"~~
And, when we compared the answers he
looked at mine and he asked " what
is that θ in these, that cancels θ--"
I said " that's the 'momentum transfer'
by the electron the electron deflected
by different 'angles'". "Oh", he said
"no, I only have the limiting 'values'
as θ approaches zero; the forward
scattering". Well it was easy enough
to just substitute θ equals zero in my
form and I then got the same answers
as he did. But, it took him six ~~years~~
months to do the case of zero momentum
transfer whereas, during one evening I had
done the finite and arbitrary momentum transfer..

That was my moment of triumph in which I realized I really had succeeded in working out something worthwhile."

Feynman stresses heuristic value of reformulating theories in very different ways — "Perhaps a thing is simple if you can describe it fully in several different ways without ~~knowing~~ immediately knowing that you are describing the same thing." Feynman says this is a possible way of defining simplicity

"Theories of the known, which are described by different physical ideas may be equivalent in all their predictions and hence are scientifically indistinguishable. However they are not psychologically identical when trying to move from that base into the unknown. For different views suggest

different kinds of modifications which might be made and hence are not equivalent in the hypotheses and generates from them in ones attempt to understand what is not yet understood."

F. ascribes idea of positron as electron going backward in time to Wheeler — all electrons are 1 "knotted" particle (But says F there are not equal no's of + & − electrons).

F remarks "The idea of the positron being a backward moving electron — was very convenient but not strictly necessary for the theory because it is exactly equivalent to negative energy ~~sea~~ point of view." (+ ...)

Nafe, J.E, ~~Nelson~~ Nelson, E.B & I.I Rabi

P.R. 71 (1947) 914–915.

"The Hyperfine Structure of Atomic Hydrogen and Deuterium".

report discrepancy in theory, experiment. 5 times greater than probable error.

Breit G. P.R. 72 (1947) p. 984.

"Does the electron have an intrinsic magnetic moment" suggests NMR result can be interpreted in terms of an intrinsic magnetic moment (Pauli type)

Kusch, Foley P.R. 72 (1947) 1256.

give preliminary evidence of % from Zeeman splitting of atomic levels in Gallium. these results indicate ... of ...

Kusch, P and Foley H.M. P.R. 74 (1948) 250–263

" The Magnetic moment of the electron.

Note that Schwinger's calculation of the anomaly
came after their measurement, but not because
of it.
These experiments were due to Breit's suggestion
of an anomalous moment — direct test
using Zeeman splitting due to suggestion of Rabi

C.H. Sommerfield (1957) P.R. 107 p. 328–29.
"Magnetic dipole moment of the electron"
reviewed results; Karplus & Kroll calc. 4th order
to $\mu_e/\mu_0 = 1.0011596$.

A. Petermann Nuc. Phys. 5 (1958) p 677–683
"Fourth order Magnetic ~~Moment of the~~
Electron"
refers to Franken, Lieber, Liebes? Pennewiss (1957)
as starting point of doubt about calculations
of 4th order corr. They found
1.001165 (11), read too high
for Karplus, Kroll.

Wilkinson D.T. & Crane H.R. P.R. 130(1963) p 852-86

"Precision Measurement of the g Factor of the Free Electron"

culmination of work initiated by Louisell, Pidd, Crane (1954), refined by Schupp, Pidd, Crane (1961) the latter experiment had errors same order of magnitude as 4th order corrections, new experiment designed to test 4th order prediction

W & C suggest not worth increasing accuracy of experiment to test α^3 terms (these terms contribute about 11 ppm, perhaps to expect in new experiment to find about 27 ppm but uncertainty is order of 5 uncertainty. But uncertainty in value of α still is ~ ~~9 ppm~~ 5 ppm, similarly for other constants involved in evaluating the data.

Wilkinson, Crane's results were re-examined by Rich & others who found a three standard deviation from theory

New experiment undertaken by Wesley, Rich brought back agreement with theory.

Wesley J.C. & Rich A. P.R. A 4 (1971) 1341 – 1363
"High-Field Electron g-2 Measurement".

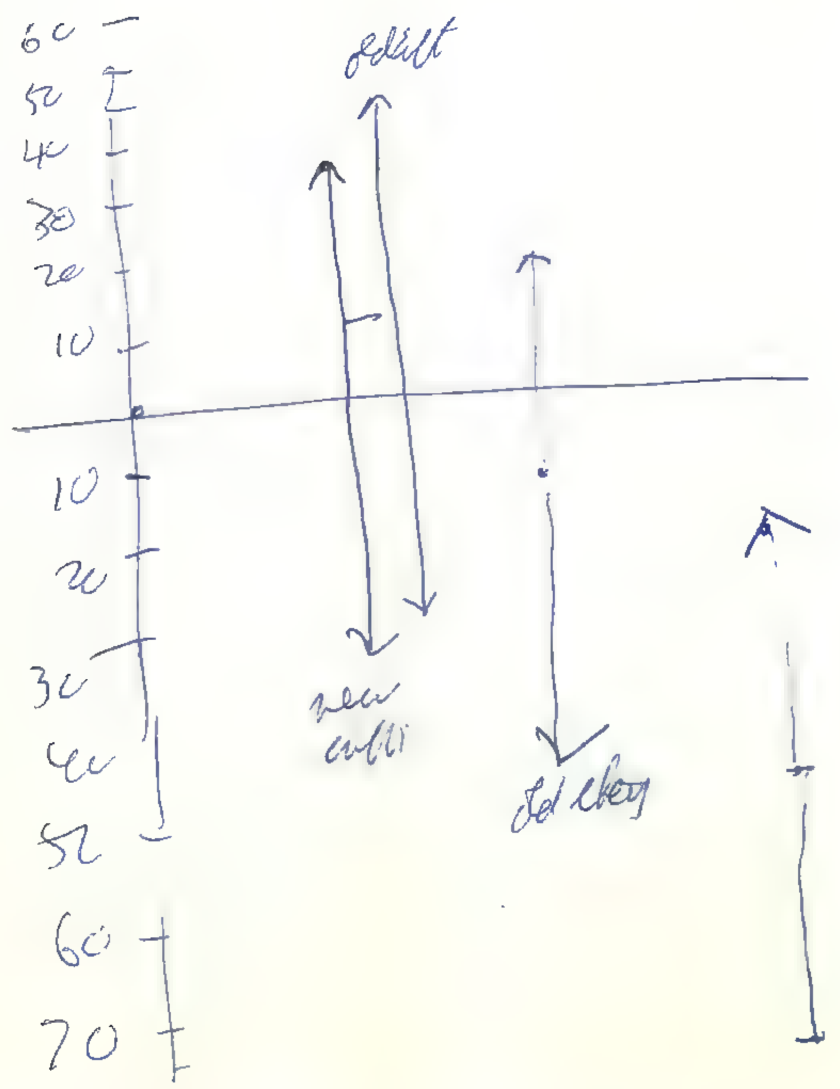
W & R improved accuracy to 3 ppm made feasible a direct test of 6th order corrections. Two calculations being worked on by 6 groups. Refer to Levine & Wright

W & R say accuracy might be increased by a factor of 2, but "we feel that such an attempt would not be worth so large investment of time & effort necessary. Accordingly we have concluded our current electron g-2 work".

W & R admit discrepancy of their result with the revised C & W "no concrete basis for the discrepancy has yet been found".

Edit
w/o edd 115965 | 77 ± 35
reversed | 67 ± 35

Uberj 4/P/de X. | 54 ± 33
2 d W. | 19 ± 25



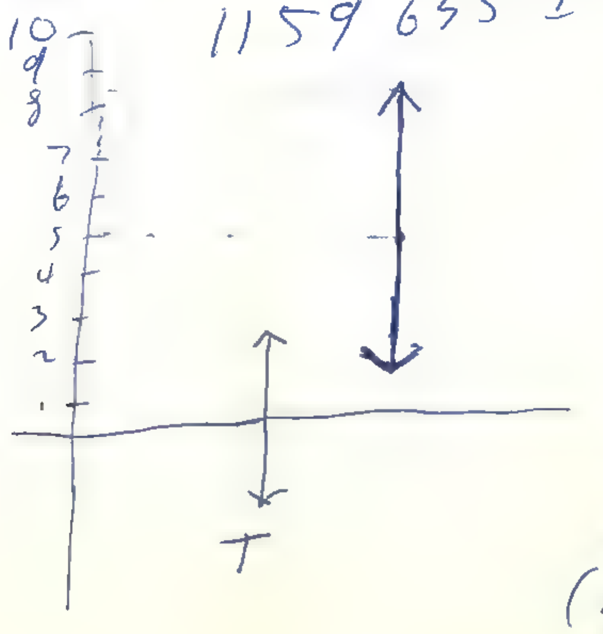
Levine, M. J. & Wright, J. P.R. D 8 (1973) 3171–3179

Anomalous Magnetic Moment of the Electron

refer to Granger, ~~[illegible]~~ Ford (P.R.L. 28 (1972) 1479
for correction of W, R value from
1159657.7 to 1159656.7 ± 3.5

they (i.e. (L & W)) revise their previous value quoted by Wesley, Rich as being too high due to an error in numerical integration for one graph.

their final result 1159651.9 ± 2.5.
compared with their previous value of
1159655 ± 2.



they (i.e. G & F) also correct Wilkinson, Crane's results, so bring these into agreement with Wesley, Rich & with theory (acknowledged in Wesley, Rich R.M.P (1972) - errors)

Combley F. and Picasso E:
"The Muon (g-2) Precession experiments: Past, Present and Future".
Physics Reports 14 C (1974) p 1–59.

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refer to next recent calculation of 8th order electron anomaly α_{13}.
Calmet and Peterman Phys. Lett. 47B (1973) 365
Levine, Wright P.R. (1973)
Cvitanovic and Kinoshita SLAC Rep. (May 1974)

they quote theoretical value:

$a_\mu = .00116589\,7 \pm 8$ Pole = ...

Expt. Bailey et al. (Nuovo Cimento A9 (1972) p 369)

$a_\mu = 0.00116\,6160 \pm 310$

Bailey et al. Phys. Lett. 55 B (1975) p. 420–424:

New Measurement of (g−2) of the muon.

Experimental value $\frac{g-2}{2}$ = 0.00 1165 895 ± 27

theory = 0.00 1165 908 ± 10

(includes 73 ± 10 from d_μ (hadrons))

Cvitanovic, P & Kinoshita T.

P.R. D 10 (1974) 4007–4031

Sixth order magnetic moment of the electron

obtain α theor. = .00 1159 651.7 ± 2.2

cf. with α exp = .00 1159 656.7 ± 3.5

(cf $P(\chi^2_{x-y}) = \int e^{-\frac{(x-x_0)^2}{\sigma} - \frac{(y-y_0)^2}{\sigma'}}\, d\cancel{x_0}$ with $y = x + \Omega$.

$$= \int e^{-\frac{(x-x_0)^2}{\sigma} - \frac{(x+\Omega-y_0)^2}{\sigma'}}\, dx.$$

$$= \int e^{-\frac{2x^2}{\sigma} + \frac{\Omega^2}{\sigma} + \frac{x_0^2 - y_0^2}{\sigma} + 2x(x_0+y_0) + 2x\Omega - 2y_0\Omega}.$$

This is most recent, probably most accurate value to date.

J. Calmet, S Narison, M. Perrottet and E. de Raphael. "The anomalous magnetic moment of the muon: A Review of the theoretical Calculations". RMP. 49 (1977) 21–29.

α_μ (theory) = 0.00 1165 920.6 ± 12.9 (
α_μ (expt.) = 0.00 11 65 895 ± 27 }
(Bailey et al 1975)

for Electron α_e (theory) = 0.00 1 159 652.4 ± 0.6 }
α_e (expt) = 0.00 1 159 656.7 ± 3.5 }
Wesley, Rich

Refer to
Levine, M.J. Perisho, R.C and Roskies, R.
(1976) Phys. Rev. D. 13, 997–

R.S Van Dyck Jr, ~~P.B. Schwinberg, H.G. Dehmelt~~.
"Precise Measurements of Axial, Magnetron, Cyclotron and Spin-Cyclotron-Beat Frequencies on an Isolated 1-MeV Electron". PRL 38 (1977) P. 310–314
quote α_e (expt.) = 0.00 1159652.4 ± 0.2

R. Haag. Dan. Mat. ~~M~~ Fys. Medd. 29 no 12 (1955), 1-37.
" On Quantum Field Theories ".
discusses difficulties connected with ∞ no. degrees of freedom – shows free field vacuum of Tomonaga-Dancoff and Dyson U(t_1, t_2) for finite t_1 or t_2 does not exist. Shows general field theories exist (i.e. commutation relations for equations are not fixed a priori) which are just as inclusive as S-matrix theories. Proves in § 2 every S-matrix can be derived from some field theory – in § 3 discusses extra restrictions if field operators commute at equal times → U(t_1, t_2) cannot exist for these theories for finite t_1 or t_2. Mathematically this is due to existence of inequivalent representations of the commutation relations in non-separable Hilbert spaces (continuum $\aleph_0^{\aleph_0}$ of orthonormal basis vectors) because $\aleph_0$ for infinite no. of oscillators and with infinite no. of states.

Hall, D. and Wightman, A. S.

Mat. Fys. Medd. Dan. Vid. Selsk. 31 (no 5) (1957) 1–39.

"A theorem on invariant analytic functions with applications to Relativistic Quantum Field Theory".

Mainly concerned with a purely mathematical result

"An analytic function of n four vector variables invariant under the [illegible] Lorentz group is an analytic function of their scalar products".

The theorem was [illegible] in

Wightman (1956)

[illegible]

Wightman, A.S. and Schweber, S.S.
P.R. 98 (1955) 812 — 837
"Configuration Space Methods in Relativistic Quantum Field Theory"
They discuss expectation of commutator relations [illegible] for free particles [illegible] to [illegible]
- Wigner's proof of equivalence of all reps.
For ∞ no's of states we have to assume also unique vacuum, but this may be inconsistent with eqns of motion. (cf Van Hove (1952)).

Wightman, A.S. P.R. 101 (1956) 860 — 866
Quantum Field Theory in terms of vacuum expectation values
introduces the Wightman-axioms for VEV's.
shows VEV's are boundary values of analytic functions, and that field theory can be recovered from properties of VEV's.

Lehmann, H, Symanzik K and Zimmermann W.
N.C. 1 (1955) 205 — 225.
"Zur Formulierung quantisierter Feldtheorien"

introduce LSZ formulation — ~~the~~ eqns contain no renormalization constants, involve only experimental masses & couplings. Advantage is "elimination of all divergent terms in the basic equations". In power-series expansion we recover "renormalized expansion" of the conventional formalism.

L.S.Z. N.C. 6 (1957) 319 – 333
"On the Formulation of Quantized Field Theories – II"
refer to fund of Källén approach
Heisenberg Z. f. Phys. 120, 513, 673 (1943).
discuss derivation of dispersion relations
– refer to Goldberger. P.R. 99 979 (1955) and define [illegible] N.C. 4 1316 (1956), Symanzik, P.R. 105, 743 (1957))
for the development of the LSZ formalism.

Greenberg O.W. "Haag's theorem & clothed operators"
P.R. 115 (1959) 706–710.
discusses more complete proof of Haag's theorem.

Matthews P.T. and Salam, A
P.R. 94 (1954) 185–191
"Renormalization".
All divergences (charge & mass) are dealt with by
counter terms so that theory is now finite
in all orders of perturbation i.e. charge renormalization
is dealt with in same way as mass renormalization,
following ideas of Gupta. Proc. Phys Soc. A64 426 (1951)
by introducing a counter term.

Lehmann, H. N.C. 11 (1954) 342 — 357

"Über Eigenschaften von Ausbreitungsfunktionen und Renormierungskonstanten quantisierter Felder.

introduces spectral representations for Δ_F' and S_F'

and discusses magnitudes of Z_2 and Z_3,

renormalized functions exist.

This a development of approach

of Källén, G. Helv. Phys Acta 25 (1952) 417 – 434. "On the definition of the renormalization constants in quantum electrodynamics"

who formulates a field theory i.e. in terms of renormalized operators.

and expresses renormalization constants in terms of renormalized fields

Källén raises two questions:

1) Is Dyson series convergent. i.e. are renormalized quantities identical finite (i.e. exist) and are not just a divergent sum of finite terms.

2.) For a sensible theory, the coupled, the Z's are

well defined and finite. Källén does not discuss whether this is true in actual example, but it is quite a separate question from no 1.

Stueckelberg E. C. G. and Petermann, A
Helv. Phys Acta 26 (1953) 499–520
"La normalisation des constantes dans la théorie des quanta"
Introduce idea of a renormalization group.

Gell-Mann, M and Low F. E.
"Quantum Electrodynamics at small distances":
Phys Rev 95 (1954)
refer to Källén Dan. Mat. Fys Medd 27, 12 (1953) 1–18.
"On the Magnitude of the Renormalization constants in quantum Electrodynamics"

e_0 may be infinite or finite (unobservable),
claims one of $Z_2^{-1} e_0^2$ and Z_3 must be infinite.
Källén says renormalization constants may

actually be finite. they only appear infinite because relevant functions are not analytic at $e \to 0$.

(cf $\cancel{\exp}(-e^2/L) \simeq 1 - \frac{e^2}{L} + \dots$ where $L \to 0$.

each term diverges.

or $\exp(-e^2 L) \simeq 1 - e^2 L + \dots$

but expected regularity at ∞

i.e. renormalization constants may be finite even if expansion is infinite.

or renormalized series may be ~~infinite~~ divergent even if terms are finite e.g. e^{-1/e^2} has no convergent power series expansion around $e = 0$.)

But Källen argues that ≥ 1 renormalization constant is in fact actually infinite in QED that the best one can hope for is that the renormalized theory is finite — he does not discuss this point in detail.

NB the argument for infinite values of at least one renormalization constant has subsequently been criticised.

Jaffé, A. Comm. Math. Phys. 1 (1965) 127–149

"Divergence of Perturbation theory for bosons"

investigates convergence of field theories in 2-dimensional space-time — finds Green's functions not analytic at $\lambda = 0$. For non-derivative couplings these theories are renormalizable and all renormalizations are finite.

~~Jaffé find~~ refers to work of Hurst (1952) Proc Roy Soc. 214 A 44 and Thirring (1953) & Petermann (1953) for $\lambda\phi^3$ theory in 4-dimensional space-time for proof of non-analyticity in DF'.

Hepp, Klaus. Comm. Math Phys. 2 (1966) 301–326

"Proof of ~~the~~ Bogoliubov–Parasiuk theorem (1957) on renormalization". A very ~~technical~~ [illegible] paper. Says Salam's criterion is not satisfied by Bogoliubov. "It is hard to [illegible] [illegible] theoreticians where understanding of the essential steps of the proof is incomplete".

W. Thirring

"On the divergence of perturbation theory for quantized fields."

Helv. Phys. Acta. 26 (1953) 33 – 52.

Refers to Dyson's physical argument.
Considers $\lambda\phi^3$ scalar theory — shows theory is renormalizable — estimates lower bound for n^{th} order graph multiplied by estimate for these graphs finds series behaves like

$$\lambda^n \frac{(n/2-2)!}{n^2} \times \text{const.}$$

diverges for all values of λ

$$\frac{a_{n+1}}{a_n} = \lambda \cdot (n+1) \times \left(\frac{n}{n+1}\right)^2 > 1 \text{ as } n \to \infty.$$

So roughly each graph $> \lambda^n/n^2$

no. of graphs $\sim n!$

$\therefore$ n^{th} term is like $\lambda^n \cdot \frac{n!}{n^2}$.

Hurst C.A. Proc. Camb. Phil. Soc. 48 (1952) 625 – 639. also derives divergence of $\lambda\phi^3$ field theories

Thirring also suggests power series in $(\lambda-\lambda_0)$ also diverges so ϕ is non-analytic for all values of coupling constant λ.

Petermann Helv. Phys Acta. 26 (1953) 291
also reaches similar conclusion.

Hurst ~~A.E.~~ C.A. Proc. Roy Soc. 214 A (1952) 254—61.
"The enumeration of graphs in the Feynman-Dyson technique".
investigates no of graphs of order n, shows rapid increase, suggests perturbation series cannot converge unless contribution of each graph goes down very rapidly with n.
contribution of graph is of order $n^{n/2}$.
Hurst concludes asymptotically.
"excellent agreement between experimental results and theoretical calculations would indicate that the series is in fact to be interpreted as an asymptotic expansion about the singular point $\lambda = 0$

P.J. Redmond . P.R. 112 (1958) 1404–1408
"Elimination of ghosts in propagators"
suggest D_F' has an essential singularity at $q^2 = 0$. He concludes Z^{-1} is finite. How then if we expand Z^{-1} in powers of q^2 do we find a series all of whose coefficients are infinite?
Redmond says $Z^{-1}(q^2)$ is not analytic at $q^2 = 0$.

Uretsky J.L and Redmond P.J.

Ann. of Phys. 9 (1960) 106–124.
"Sn. out-formalism for renormalizable quantum theories" ... N.P. model treated à la LSZ with Bureau properties of N.P. models – theories some light on LSZ in rel. theories – does not discuss essential singularities.

Hori S. Prog. Theor. Phys. 8 (1952) 569–570.
(letter) "On the Convergence of the S-Matrix Series"

refers to Dyson (1952) and accidentally confirms Hurst's estimate for No. of graphs, but does not estimate lower bound for contribution from each graph, as e.g. in Thirring's work.

R. J. Riddell "The Number of Feynman Diagrams"

P.R. 91 (1953) 1243–1248.

Riddell confirms Hurst's estimate for No. of relevant graphs $\sim n^{n/2}$. Concludes series is not absolutely convergent. "Size of coupling constant seems to have little to do with the convergence of the theory (although it would on asymptotic expansion of the theory)" determine the usefulness of the theory)"

Could series be conditionally convergent due to cancellations between terms (i.e. of fixed order n) — very difficult nth order term of point to investigate. If series is conditionally

convergent " Padé-type approximations based on rearrangements of the series seem of doubtful validity."

Dyson F.J. P.R. 85 (1952) 631–632.

"Divergence of Perturbation Theory in Quantum Electrodynamics"

Dyson's argument for divergence of $F(e^2) = a_0 + a_2e^2 + a_4e^4 + \dots$ for any physical quantity F

Take $e \to ie$. If F is absolutely convergent so $F(-e^2)$ but this does cannot be expected to converge (correspond to a well-defined function") since we are now in a world where opposite charges repel. So we can get an "explosive disintegration of the vacuum by spontaneous polarization". Repulsive energy of pairs can be greater than the rest energy if roughly $\frac{(ne)^2}{a} > nmc^2$

or $n > \frac{mc^2}{e^2}a$. Take $a = \hbar/mc$ then $n > \frac{\hbar c}{e^2} \simeq 137$.

Dyson argues that terms will decrease and then increase without limit at the critical value of $n \simeq 137$.

Dyson goes on to argue. there are 2 alternatives

A $F(e^2)$ is well-defined by non-perturbative methods with asymptotic expansion $F(e^2) = a_0 + a_2 e^2 + \ldots$ but the series is not sufficient by itself to define $F(e^2)$ uniquely

B Formalism only gives us coefficients $a_0 a_2$ etc and hence formalism does not determine $F(e^2)$ — so new physical theory is needed to find $F(e^2)$ — Dyson's says B has attractive features — would need radical revision of Q.E.D. with need to extend theory to deal with meson phenomena etc.

Hurst Proc Camb Phil Soc. 48 (1952) 625-639 cited. "A divergent Perturbation Expansion in field theory"

quote " Error in stopping calculation at any order of approximation is of smaller order than last term calculated.

$z=0$ cannot be a singular point for an asymptotic expansion but would be an essential singularity, which may or may not be isolated. In this case the asymptotic expansion would be valid only in a ~~sector~~ $|\arg z| < \theta$, $\theta \leq \pi$ and error cancellation by stopping at some order of approximation would not be capable of indefinite reduction by calculating further terms. " The difference between an asymptotic and a convergent series lies more in the theoretical than in the practical consequences, for large complex variables would lead to a series which effectively ~~orders~~ useless defined for calculations whether series was "asymptotically or was convergent.

" For a convergent expansion, i.e. z in a fixed period, the error could be made as small as one pleased by increasing n, but for an asymptotic expansion the error would only be decreased to a non-zero lower limit, and then computing further terms, the error would begin to rise again".

Low, F.E. P.R. 97 (1955) 1392 – 1398

" Boson-Fermion Scattering in the Heisenberg Representation"

derives the Low equation by direct manipulation

Chew G.F. and Low F.E. P.R. 101 (1956) 1570 – 1579

" Effective-range approach to the Low-Energy p-wave Pion-Nucleon Interaction".

Reduces Low eqn using Wick's method (R.M.P. 27 339 (1955)) and applies to obtain effective range approximation for P-wave phase shift.

Essentially C & L have a forward + backward relation when they approximate by neglecting all but P-waves. Resulting equation is not a partial wave dispersion relation for the P-waves, which allows for coupling in of all higher partial waves.

Oehme R. P.R. 100 (1955) 1503 – 1512

" Dispersion Relations for Pion-Nucleon Scattering.

I. The Spin-Flip Amplitude"

consider dispersion relations off the forward direction (actually for derivatives w.r.t. t at forward direction).

and ~~use~~ it in the unitarity equation or just Low's equation. If we neglect contribution from phase shifts ≥ 1.
Low's equation, no wrinkle, because "where does not exact dispersion relations for amplitudes corresponding to unbounded angular momenta".

Oehme R. P.R. 102 (1956) 1174 – 1180
"Dispersion relations for Pion-Nucleon Scattering: No-Spin-Flip Amplitude".

Again Oehme first derives dispersion relation — then makes 3 assumptions neglect recoil of Nucleon, neglect any nonstatic states > 1, neglect inelastic processes.
— and arrives at Low's equation.
In final section of paper Oehme remarks he has derived dispersion equations for unbounded angular momentum amplitudes but says he cannot find exact dispersion relations for unbounded angular momenta

— in effect he has not put in enough information except an approximation of simply neglecting any interaction with the higher angular momentum states.

<u>Chew G.F., Goldberger, M.L., Low, F.E. and Nambu, Y.</u>

P.R. <u>106</u> (1957) 1337 — 1344

"Application of Dispersion Relations to Low-Energy Meson-Nucleon Scattering"

Describe 2 uses of dispersion relations

1.) Experimental check of forward dispersion relations by measurement of several quantities

2.) Neglecting higher waves than $l = 1$, derive Chew-Low equations as an [illegible] of [illegible] but in static limit.

CGLN unable to affect the validity of the static limit, but CGLN' <u>allow for the effect of recoil</u>.

Mandelstam, S. P.R. 112 (1958) 1344 — 1360.

Suggested that dispersion relations could replace eqns of field theory ascribed to Gell-Mann at Rochester Conference vi (1956.

Mandelstam introduces his double dispersion representation "the simplest assumption we could make is that it [the amplitude] is analytic in the entire space of the two variables [s, t] except for cuts along certain hyperplanes" [determined from unitarity]. Assumption is a generalization of a representation due to Nambu (1955), but Nambu's rep. is invalid in perturbation theory, whereas M's representation "has not been shown to be invalid" — quotes examples of perturbation terms which do have this representation.

He then emphasises the Mandelstam iteration as a practical programme. Title of paper is "Determination of the Pion-Nucleon Scattering Amplitude from Dispersion Relations and Unitarity. General Theory". M. argues. ~~one~~ symmetries that and in all orders of perturbation theory amplitude is

Need to extend to be proved in full from unitarity. Extra conditions of Regge poles? by unitarity.

Mandelstam S. Rep. on Prog. in Physics 25 (1962) 99–162.
"Dispersion relations in Strong-Coupling Physics".
general review article.

Discusses CGLN approach of including just a few partial waves in fixed-t dispersion relations. Contrasts phenomenological application and dynamical application — "How much information is taken from experiment — two approaches shade towards one another if arbitrary parameters introduced to approximate unknown effects in the dispersion relation which are then used to fit experiment. However in practice one finds a difference between the types of calculation which characterise the two approaches." (p122)

Mandelstam formulates Principle of Maximum analyticity thus "the scattering amplitude is analytic in all its variables except at those points where singularities arise as a consequence of the unitarity condition" (p130)

on p.158 M says approach is from "point of view of local field theory" He attacks pure S-Matrix approach. "though quantum field theory may

contain operators which do not correspond to measurements, the S-Matrix theory seems to go too far in the opposite direction and to contain less than could actually be measured" . . . "Another objection is that assumptions about the possibility of analytically continuing our functions are rather artificial unless they are derived as mathematical consequences of some other postulates"[4]. Our present quantum field theory, ~~not~~ in spite of its inadequacies, is based on well-worn concepts of classical field theory and quantum mechanics and would appear to be more natural. This, needless to say, is a matter of opinion about which it is difficult to argue and, in any case, one may maintain that such considerations should play no part in formulating a theory. One must keep an eye on all possibilities with regard to making a radical extension of the theory which all agree is necessary".

R. says there will "always be an uncertainty whether discrepancies [with experiment] were due to the failure of the approximations or of the dispersion relations themselves"

Mandelstam S. P.R. 115 (1959) 1741—1751.

" Analytic Properties of Transition Amplitudes in Perturbation Theory":

Says double dispersion relations "have not thus far been proved from the general principles of quantum field theory". 4th order perturbation term

are investigated and shown to have the required representation provided the masses do not allow anomalous thresholds (cf the general anomalous thresholds of second type in classification of Karplus, Sommerfield & Wichmann (P.R. 114 376 (1959)) writes "the double dispersion representation breaks down, and there will be singularities in the complex plane".

~~Goldberger M.L.~~ Gell-Mann, M. Goldberger M.L. Thirring W.E.
P.R. 95 (1954) 1612–1627.
"Use of Causality Conditions in Quantum Theory".
refer to link between causality and scattering amplitude relations going back to Kramers (1927) and Kronig (1926) [J. Opt. Soc. Am. 12 547 (1926)] also ~~Kramers~~ Kronig, Physica 12 543 (1946) suggested causality requirement should be imposed in addition to Lorentz invariance and unitarity on the S-matrix.
G G and T deduce forward scattering dispersion relation for photons by nuclei. They use perturbation theory to estimate required analytical properties.

Goldberger M.L. P.R 97 (1955) 508–510
derives exact dispersion relation, not using perturbation theory for the case of photon scattering in forward direction. Title is "Use of Causality conditions in Quantum Theory"

Goldberger M.L. P.R. 99 (1955) 979–985.
"Causality conditions and dispersion relations. I. Boson fields"

treats case of forward scattering of bosons with finite rest mass

Toll J.S. P.R. 104 (1956) 1760–1770.
"Causality and the Dispersion Relation: Logical Foundations".

derives dispersion relation for general causal linear systems with time-independent connection between output and a freely variable input. refers to applications in optics to Wood & Herzfeld Handbuch der Physik (1928) vol. 20 ch 10 p 480, Kronig & Kramers, Kronig RMP 4 471 (1932) and applications in electrical network theory.
Toll gives simple physical picture of dispersion relation. Scattering absorption process contributes to coherent scattering amplitude as 2 stage process i.e. absorption + re-emission

Imag. coherent amplitude relates to real absorption
= absorption amp × re-emission amplitude

→ Im forward scattering = Total cross-section.

Real coh. amplitude relates to virtual absorption
and is expressed as sum of (emission × absorption)
over all intermediate states
this is just the dispersion relation.

Mandelstam, N.C. 15 (1960) 658–685.

"Some Rigorous Analytic Properties of Transition Amplitudes"
discusses double dispersion relations from
part of axioms of general field theory
– proves analyticity in a certain domain
– via general proof of the Mandelstam
representation achieved

Mandelstam S. Ann. Phys. 21 (1963) 302–343

"Regge Poles as Consequences of Analyticity and Unitarity"

M. discusses proof of analyticity in J if double dispersion relation is satisfied — part of success of Regge's original programme.

He states on p. 313 that ~~to prove~~. The necessary absence of c.m. ambiguity. It does not discuss equivalence of c.m. ambiguity and assumed analyticity of c.m. ambiguity and assumed analyticity of 2nd Regge sheet specifically, but his derivation appears to imply this.

Donnachie, A, Hamilton J and Lea A.T.
P.R. B135 (1964). 515–539.

"Predictions of p, d- and f- wave pion-nucleon scattering"

use partial wave dispersion relations to get π-N phase shifts with input of experimental values of resonances in crossed channels (so this is not a bootstrap situation)

Donnachie A & Hamilton J. Ann. Phys. 31 (1965) 410–435

"The Quantum numbers of the Nucleon Isobars".

continues the DHL programme with analysis of $N, N^*, (\pi\pi)_0, \rho$ as dominant contributions.

Hamilton J and Woolcock, W.S. R.M.P. 35 (1963) 737–787

"Determination of Pion-Nucleon Parameters and phase shifts by Dispersion Relations".

Extend CGLN to determine coupling constants etc (i.e. they are fixed by dispersion relations)

H & W state main limitation is convergence of numerous of Legendre series. (cf CGLN)

Donachie, A. Rep. Progr. in Physics (1973) 36 695-753.
"Partial Wave Analysis and Baryon Resonances".
General phenomenological review, no detailed dynamical calculations.

Chew G.F. and Mandelstam S. P.R. 119 (1960) 467-477
"Theory of the Low-Energy Pion-Pion Interaction".
Derives partial wave dispersion relations derived from Mandelstam representation. Solutions N/D method of soln. "They refer to C.D.D. ambiguity" They correspond to theories in which, before the coupling is turned on, there are one or more particles with the same quantum no's as two pions. Once the coupling is turned on, these

particles become unstable and appear experimentally as resonances. These "kinematical" resonances differ from "dynamical" resonances . . . in that they occur for arbitrarily small values of the coupling constant. The absence of such unstable particles must be regarded as an additional postulate to be inserted into the theory"

Chew G.F., Mandelstam S. and Noyes H.P.

P.R. 119 (1960) 478 – 481.

"S-wave dominant solutions of the Low-Chew [illegible] equations". continues the Chew & Mandelstam paper (1960) and introduces the phrase bootstrap

"this would be a "bootstrap mechanism; i.e. the force producing the P-wave resonance would be due to the exchange of a resonating P-wave pion pair". In effect the ρ-resonance is being bootstrapped.

Chew G.F. & Frautschi S.C. P.R.L. 7 (1961) 394-397.

"Principle of Equivalence for All Strongly Interacting Particles within the S-Matrix Framework".
They refer to C.D.D. ambiguity but claim some C.D.D. poles may not correspond to elementary particles. They start from Regge theory. Pole position $\alpha_i(E)$ is analytic function of E. If "$\alpha_i(E)$ = const." ~~is not allowed~~ turns out to be "not allowed".
They refer to Feynman for idea that correct theory should not allow a decision as to which particles are elementary. They refer also to Heisenberg (RMP 29 269 (1957)) for idea of "an underlying spinor field that corresponds to no particular particle but which is supposed to generate all the observed particles on an equivalent basis". C & F postulate "all poles of the S Matrix are Regge poles." i.e. moving poles in the j-plane. "This is a natural

extension to angular momentum of the
maximal analyticity principle which heretofore
has been applied only to linear momenta".
"Maximal analyticity in linear momenta fails to
specify precisely the asymptotic behavior in
momentum transfer, which is the controlling
factor in determining the region
of analyticity in the J plane" (in Froissart)

Experimental test of hypothesis that all
all particles are Regge trajectories connected
with high energy scattering cross-sections in
crossed channels.

Elementary particles give asymptotic
behavior $\alpha(t) \to$ S = const. 10.
the difference should show up
experimentally (shape of peak does not
change with energy for example).
~~Nucleons~~ why low mass particles
have low spins.

Regge - T. N.C. 14 (1959) 951–976

"Introduction to complex angular momentum".

Introduces complex j in N.R. scattering theory — increases range of validity of dispersion relations — he can derive Mandelstam representation.

(Mandelstam rep. also derived for potential scattering independently) by Blankenbecler, Goldberger, Khuri and Treiman, Ann. Phys. 10 (1960) 62-93)

Zachariasen F. and Zemach C. P.R. 128 (1962) 849–858

"Pion Resonances".

discuss the ρ – bootstrap

ρ exchange gives attractive force between 2 pions to produce the ρ resonance.

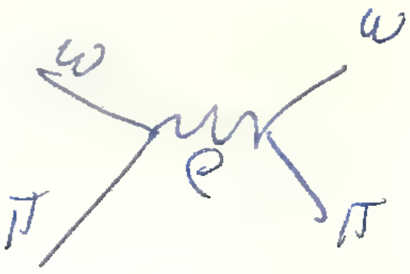
Full bootstrap v. difficult. e.g. we say that π – mass is given in $\rho = \pi\pi(\rho)$

Also we should treat Regge families not just single particles. In addition we ignore other Regge approximation behaviour (replace by phenomenological cutoff for example to reproduce effect of Regge behaviour in making amplitudes less singular at large energies)

Refers to early calculation of Chew & Mandelstam (1960). Z and Z now consider also $\pi\pi \to \pi\omega$ and $\pi\pi \to K\bar{K}$. They ignore the $K\bar{K}$ channel but include the effect of the ω. Effect of ω very important. Z & Z consider only ρ exchange but include the effect of the ρω channel

and

or



Z, Z find $m_\rho \approx$ 659 MeV.
cf. with expt. value 767 MeV.
needed for widths.

without the ω channel
Z, Z find $m_\rho =$ 350 MeV
taking $\rho = \pi\pi(\rho)$ alone

Z, Z also consider the problem
of the ω as a resonance in $\rho\pi$
scattering. Z, Z use a cutoff
that results are fairly insensitive
to its exact magnitude.

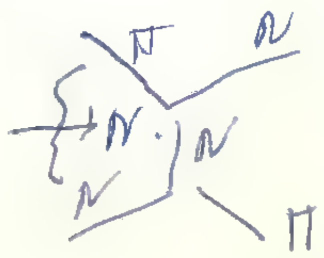
Abers, E. and Zemach C. P.R. 131 (1963) 2305—2318.

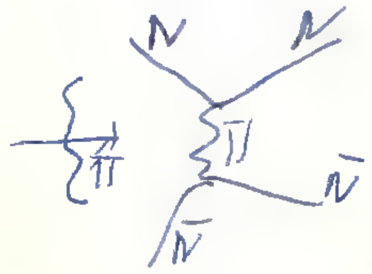
"Bootstraps and the Pion-Nucleon System".

Fairly general introduction to the bootstrap philosophy.

In bootstrap forces are, in fact, so strong that the binding energy of the "composite" nucleon {(N+π)} is comparable to the masses of the constituents themselves. This is the essential feature that permits a particle to appear as a constituent in a composite state and as the composite state itself, thus obscuring (though not invalidating the analogy) to loosely bound states such as the hydrogen atom or an atomic nucleus.

Simplest case of a bootstrap resonance model i.e. $N = \pi N(N)$ and $\pi = N\bar{N}(\pi)$

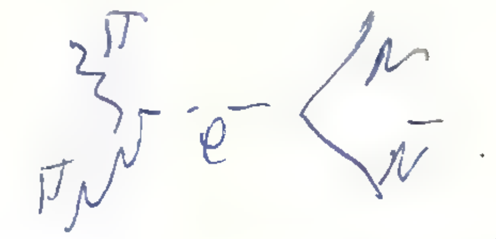




But N exchange is too weak to bind πN system.

Also π is very deeply bound state of $\Lambda\bar{\Lambda}$ we should start with $\pi = \pi\rho$ $\pi = K\bar{K}$ as dominant effects.

A, 2 include effects of N and N^* exchange and also ρ exchange?
in crossed channel $\pi + \pi\ (\rho) = N + \bar{N}$.



Results for masses, widths of Λ, N^* depend on cutoff's — reasonable values for cutoff's / due to neglect of ρ balance) and give present and unfavourable values.

2, 2 refer to Chew (P.R.L. $\underline{9}$, 233 (1962)) for original suggestion of the "reciprocal bootstrap" mechanism.

Kramers H.A. Atti. Congr. Intern. Fisici, Como, 2 (1927) 545–557.

" La Diffusion de la lumière par les atomes".

K. derives connection between refractive index and absorption coefficient for scattering of light in the form of a dispersion relation
- says he worked this out in an unpublished paper in 1925. Refers to independent discovery by Kronig in 1926 (J. Opt. Soc. Am. 12 547 (1926)).

~~Krame~~ Kronig R. de L. Physica 12 (1946) 543–544

In a letter to editor entitled
" A Supplementary Condition in Heisenberg's theory of elementary particles"
refers to H's discussion of S-matrix - what follows in Ed. of future theory must be related
- refers to Kramers, Kronig relations for scattering of light by atoms from causality.
" It here would seem reasonable to

postulate for the scattering of particles a connection between the real and imaginary part of the scattering amplitudes of the same type as in optics".

J. Hamilton Prog. in Nuclear Phys. 8 (1960) 143-194.
"Dispersion Relations for Elementary Particles"

H. gives very good general review of dispersion relations in classical physics. e.g. Complex ... index $\Omega(\omega) = 1/z(\omega)$

then $\mathrm{Re}\,\Omega(\omega) = \frac{2}{\pi} P \int_0^\infty \frac{\omega' \,\mathrm{Im}\,\Omega(\omega')}{\omega'^2 - \omega^2} d\omega'$,

$\mathrm{Im}\,\Omega(\omega) = -\frac{2\omega}{\pi} P \int_0^\infty \frac{\mathrm{Re}\,\Omega(\omega')}{\omega'^2 - \omega^2} d\omega'$

derived earlier from formula for $z(\omega)$ by circuit analysis, & by general argument of causality. Use reality relation $\Omega(\omega) = \Omega^*(-\omega)$ to change from $\int_{-\infty}^{\infty}$ to $\int_0^\infty$ in dispersion relation.

Sum rules obtained by letting $\omega \to \infty$ in dispersion relation,

H. also discusses scattering of light by an atom by detailed model and by causality argument.

H next discusses applications to particle physics — esp. M. Gell-Mann's representation is not derived from causality but is "deduced from a very general hypothesis about the analytic properties of scattering amplitudes when not only the energy but also other variables (such as the momentum transfer) become complex".

H discusses Forward & Total cross-sections at all energies we can compute the forward scattering amplitude and compare with experiment — good agreement — used in other phenomenological applications.

H. discusses problem of proving such general dispersion relations "It may be that in order to prove the relation for larger values of the momentum transfer, we shall have

to me much more detailed knowledge
about the interaction"

~~Haag~~ Brenig W & Haag R. Fortschritte der Physik
I (1959) 183–242.
"Allgemeine Quantentheorie der Stossprozesse"

Gives general mathematical discussion of scattering theory in German.

W. Heisenberg Z. f. Phys. 120 (1943) 513–538.
"Die "beobachtbaren Grössen" in der Theorie der Elementarteilchen."

Part II of this paper in same vol. pp. 673–702.

H. discusses fundamental topics and says he is looking for principles which will remain valid in a future theory (cf. principles Einstein's applied to special relativity) and he believes the general principles of this paper will survive in any future theoretical development.

Kronig's (1946) comment on H cont^d

"Heisenberg has investigated the problem in what respect the quantum theory in its present form will have to be modified in future and which of its features ~~will~~ certainly will have to be retained thus determining what might be called upper and lower limits between which the ultimate theory must lie.

--- Since the object of ~~this~~ note to point to a further restriction which it seems plausible to impose on any future theory" ... criterion which has to do with extending dispersion relations as an condition on the scattering matrix. (~~directly~~ but expressing indirectly a principle of causality which he takes to be the significance of dispersion relations in classical physics).

R. J. Eden "Regge Poles & Elementary Particles"
Rep. Prog. Phys. (1971) 34 995–1053.

Gives very good review of Regge theory including with introduction to F.E.S.R., duality and the Veneziano representation.

Bailin D "The theory of weak interactions in Particle Physics"
Rep. Prog. Phys. (1971) 34 491–599.

Very good general review of weak interaction physics – generalized search on T-violation in $K_L \to 2\pi$ as well as 3π – decays possibility of a superweak T-breaking interaction. Discusses the 1964 Fitch & Cronin experiment.

Stapp H.P. P.R. D3 (1971) 1303 — 1320.
"S-matrix interpretation of quantum theory"

Stapp stresses S-matrix makes all predictions that are possible in quantum theory. We must not "interlock" too strongly with observed system for observation to make sense. S. discusses Bell's theorem and discusses [illegible] [illegible] a "web" philosophy as Stapp calls it. He draws analogy with Whitehead Process & reality.

S refers to link between analytic properties assumed in S-matrix theory and the principle of macro causality which says "Every reaction is [illegible] over macroscopic distances only by physical particles; any transfer of energy-momentum not [illegible] by [illegible] of physical particles has a probability that falls off exponentially under space-time dilation".

Stapp recommends a "pragmatic" attitude towards [illegible] of QM — expressed in S-matrix approach.
S claims analyticity → macro causality but not micro causality

Equivalence between analytic structure and macrocausality is proved in

D. Iagolnitzer & H.P. Stapp.
Comm. Math. Phys. 14, 15–55 (1969)

"Macroscopic Causality and Physical Region Analyticity in S-Matrix Theory".

Equivalence is two-way.

Fund's says general analyticity may not be derivable from field theory with macro causality – macro and micro causality are two quite separate principles. These macro causal can be used to justify the normal analytic structure in the physical region. W/o regions in addition a finite [illegible] to extend the general analyticity [illegible] domain of analyticity.

Stapp says it is still an open question whether "normal analytic structure is all we need consistent with unitarity" – or extra conditions such as macro causality may be needed.

D. Iagolnitzer: The S Matrix (Amsterdam: North Holland) 1978

link between analyticity in physical region & macrocausality derived in Iag. & Stapp Comm. Math Phys 14 (1969) 15, based on Chandler & Stapp J Math Phys 10 826 (1969)

Wanders N.C. 14 (1959) 168.
Omnes P.R. 146 (1966) 1123
1st treatment of macrocausality.

I. contrast traditional heuristic approach to analyticity due to
Gunson J. Math Phys. 6 827, 845 (1965)
Stapp. P.R. 125 (1962) 2139
Olive P.R. 135 B (1964) 745.

discuss CPT & Spin-Statistics Theorem

and Bloxham, Olive and Polkinghorne
J. Math. Phys. 10 (1969), 494, 545, 553.

I. says proofs here are incomplete and indeed incorrect due to absence of "needed" [illegible]

and mathematical tools[4]. (p245)

Juncon J. "Unitarity and on-Mass-shell Analyticity as a Basis for S-Matrix Theories. J. Math Phys. 6 (1965) I. p 827–844
II. p 845 – 851
III p. 852 – 858.

a. attempts to establish maximal analyticity as a consequence of unitarity + on-mass-shell analyticity.

Olive D.I. P.R. 135 B (1964) 745–760.
"Exploration of S-Matrix Theory"
discusses. "hierarchical structure of S-matrix singularities — generate sequence of singularities by "feeding up" from what we already have.
To proceed we only have to assume [illegible] theory properties of [illegible] [illegible] [illegible] [illegible] particles etc. Olive's [illegible] singularity structure
" We cannot deduce the fundamental theorems and we [illegible] the fundamental theorems and we cannot deduce the fundamental theorems without

the singularity structure. the [illegible] circle is a fundamental obstacle to the deductive approach to S-Matrix theory. ... we -- set up a scheme of successive iterations in terms of the singularity structure of the S-Matrix. The singularity structure that can be deduced is used to derive the fundamental theorems within this "approximation" and then these theorems are used within their "approximation" to generate further singularity structure and so on.

Gale, G. "Chew's Monadology."
J. Hist. of Ideas 35 (1974) p. 339 – 348

Gale draws analogies between Chew
of Leibniz. Each monad mirrors the
whole universe — ep each particle involves
every other particle.
Everything decided on only possible one
by self-consistency. ep Leibniz
never built possible worlds. L
required a "Principle of Perfection"
to provide an overarching criterion
of choice between the systems".
Gale stresses Chew says there is
only one self-consistent system (bootstrap)
while Leibniz admits the possibility
of other self-consistent possible worlds
Also we cannot [illegible] have there
is no causal interaction between
monads.

Chew G.F. Science (1968) 161 p 762–765 "Bootstrap: A scientific idea?"
Physics Today (1970) 23 October 23–28. "Hadron Bootstrap: Triumph or Frustration?"

2 popular articles:
insistence self-consistency
"Nature is as it is because this is the only possible nature consistent with itself" (cf Leibniz all truths are analytic → Sufficient reason.

Bootstrap idea much older than particle physics

Prerequisites for Science
1) 3 D space & time (understood)
2) separate macroscopic "objects"?
3) gentle forces (e.m.) allow use "object" to serve as "measurement"
4.) existence of objects yet conflict → consciousness of measurement
explanation of all concepts would be unsatisfying
– some unquestioned framework required.
Partial Bootstrap in line with progress in science

Existence of consciousness is necessary to self-consistency in whole bootstrap.

Opposed views 1) elementary constituents of matter
2) fundamental eq. of motion

P.T.O.

Bootstrap → no arbitrary parameters

3 rules for hadrons: 1) constituent of a composite
2) exchange → force holding composite together
3) whole composite itself.

But R.F. early on not mean of constituents
simplest contained model rules 1), 2) & 3)
lead to fundamental

Tests of Bootstrap: 1.) Proof of consequences very difficult mathematical problem

2) hadrons are Regge poles – ~~all~~ lie on all particles lie on Regge recurrences ~~as~~ given by necessary Frautschi (1968)

Quarks might also lie on the Regge poles

(Chew refers to chiller & S-matrix for relating higher location of the Landau branch points to causality (macro))

As part of his course in the philosophy of science Dr Redhead will give a series of lectures on the Philosophy of Space and Time beginning on Wednesday 5th February at 2.15 pm in the Seminar Room.

The course will include ~~an~~ an introduction to the conceptual problems of the special theory of relativity.

But even if bootstrap true could also not be a beneath nuclear matter, a basic field field obeying a simple "master eq" of motion (cf. Heisenberg) → not inconsistent with the bootstrap : hadrons made of hadrons made of quark field.

<u>difficulty of bootstrap</u> is lack of a definite starting point — no single hadron can be understood without all the others but fields we can approach the complete picture in a series of approximations. bootstrap is a series of approximations covering wider & wider regions of the S-matrix.

<u>Complete bootstrap</u> long range central force. excludes existence of [illegible] [illegible] from which remaining approaches is excluded — complete bootstrap involves incorporating the classical concept of observation & possibly, even, of consciousness.

In Physics Today article,
clear offense the fundamentalist view } (F)
and the bootstrapper view } (B)

(F) understands nature in terms of fundamentals
(B) . . . . . . self-consistency

0 - arbitrary parameters [illegible] on F
[illegible] B }.

The "fundamental" concept is [illegible] [illegible],
also to the Bootstrap [illegible]

Failure of achieving a partial bootstrap
may be because only consistent S-matrix is
the full hadron bootstrap with all particles
included.

" I would find it a crushing disappointment if in 1980
all of hadron physics could be explained in
terms of a few arbitrary entities — we should
then be in essentially the same position as in 1930,
. . . To have learned so little in half a century
would to me be the ultimate frustration "